ENERAL ELECTRIC

Review

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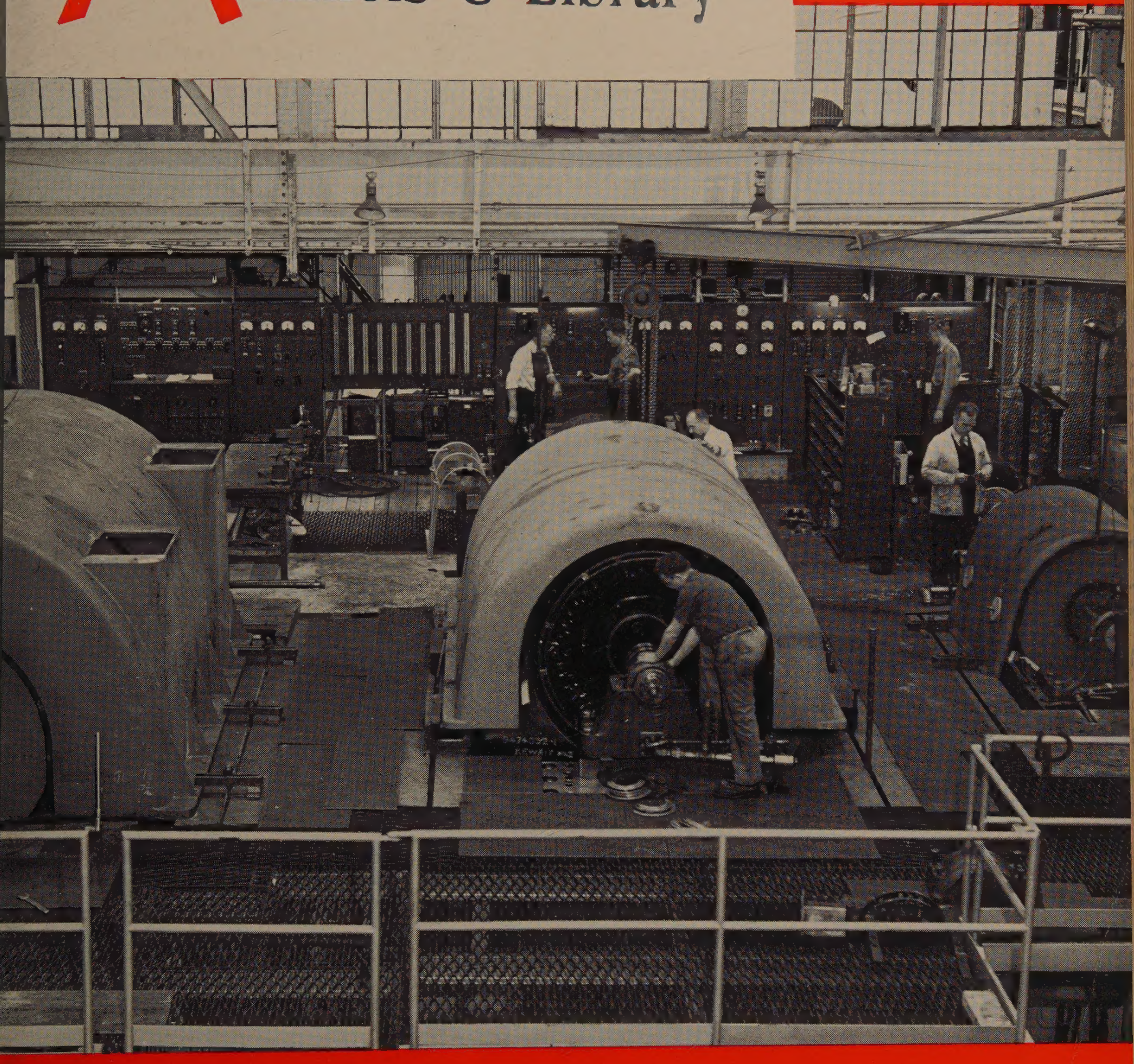

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June 1951

VOL. 54 NO. 6

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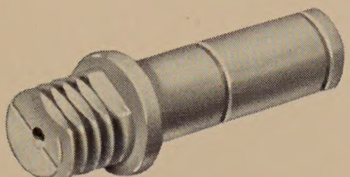

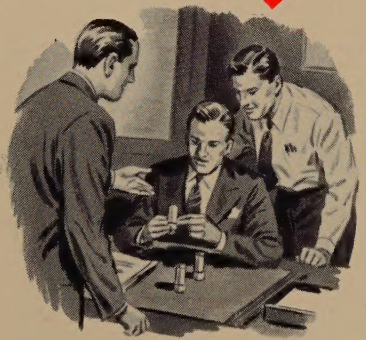

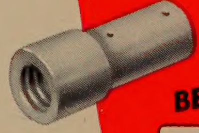

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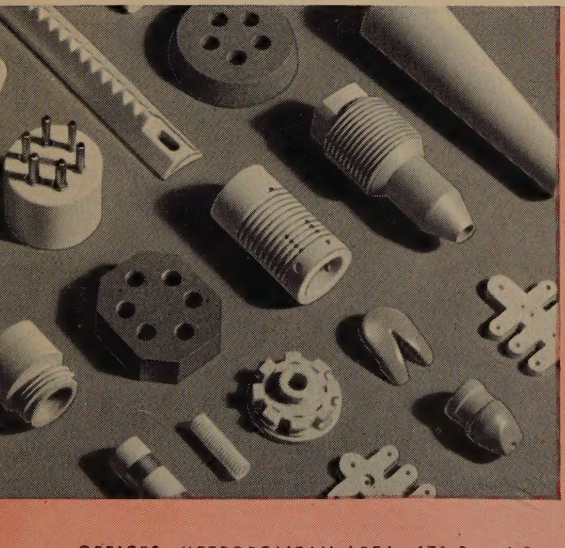

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GENERAL ELECTRIC *Review*

JUNE, 1951
Vol. 54, No. 6

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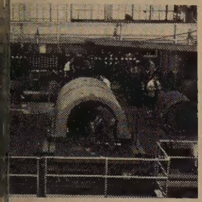

THE COVER

ine generators must meet exacting perform- quirements. These three generators are being led for no-load testing on the dynamometer nd at General Electric's Lynn River Works. able base parallels allow machines ranging 000 to 20,000 kw in rating to be readily as- d to the dynamometer drives. Here the gen- are finely balanced, and are given electrical or performance and quality. Later they will with their driving turbines for final operating s a unit before shipment. (*See p. 53.*)

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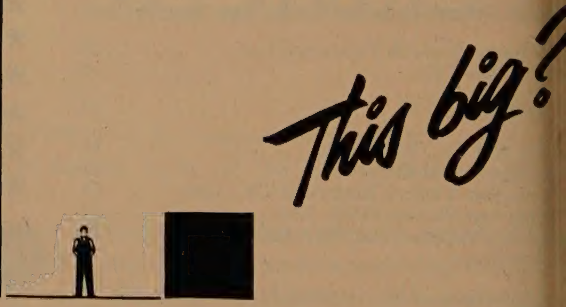

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602-200

AWARD FOR ACCOMPLISHMENT

**Robert B. Dome, Electrical Consultant for the General Electric Receiver Division at Syracuse, rece
the annual Morris Liebmann Memorial Prize, awarded by the Institute of Radio Engineers, in rec
nition of "his contribution to the intercarrier sound system of television reception, wide-band pha
shift networks, and various simplifying innovations in FM receiver circuits." The presentation
made by IRE President I. S. Coggeshall (standing, left) at the Annual Banquet in New York, Ma
21, 1951. Others present (seated, left to right) are: Donald McNicol, Consulting Communica
Engineer; Alois W. Graf (Toastmaster), Patent Lawyer; J. Howard Dellinger, Radio Consultant
Advisor; Dr. Alfred N. Goldsmith, Editor, *Proceedings of the I.R.E.;* Dr. W. R. G. Baker, Treasu
of IRE, Vice-president of General Electric Company; and Dr. Ernst F. W. Alexanderson, Consult
Engineer, General Electric Company**

GENERAL ELECTRIC Review
JUNE
1951

RECOGNITION

OGNITION is one of our noblest words. It
ndergirds all human relations. It brings a con-
ness of individual worth. It encourages. It in-
It exhilarates. It is the open sesame to even
r achievement. Like mercy it is twice blessed;
seth him who gives and him who receives.

this issue of the REVIEW we are recognizing
t B. Dome who was awarded the Morris Lieb-
Memorial Prize—1951 by the Institute of Radio
eers at the recent Annual Meeting of the In-
in New York. And thus, also, we recognize
nant-Colonel Morris Liebmann, an executive
er in the early radio industry who was killed in
while leading his men in a charge at the battle
in Flanders, August 18, 1918. His memory has
preserved by a donation from E. J. Simon, a
of the IRE. In recognizing these men we recog-
e engineering manhood of today.

ert Dome, since his graduation from Purdue Uni-
in 1926, has been active in the development of
nd novel electronic circuits, devices, and systems.
lds 67 patents. He has authored six papers in the
cal press. His latest article in *Electronics* for
nber 1950 on "Frequency Interlace Color Tele-
" describes his recent work with a fundamentally
imultaneous system of color television. He has
received the General Electric Company's highest
, the Coffin Award. He has been active in pre-
g to his engineering associates educational courses
lio theory and television principles, and in 1948
s awarded the Fellow Grade of the IRE "for his
technical contributions to the profession, and for
complishments in the training of young engineers."

s represents the finest of service, giving of one's
s to the training of young engineers. And it is
has made the engineering profession great, for
who have gone before have ever continued in their
e to those who have come after. This is attested
awards throughout engineering life, from school
on. Recognition of service is fundamental to the
er.

in the enormous extent of the contributions of
ientists and the engineers, reaching into every
e of the existence of mankind, it is easy for the
ition of the individual to become lost. I remember
er, presented before the AIEE, titled "Origin of
lectric Motor." The author, Professor Micha-
, told the story of Thomas Davenport. Born in Williamstown, Vermont, 1802, he early started his own blacksmith shop in the Town of Brandon, Vermont. Hearing of an electromagnet in Crown Point, New York, which had been invented by Professor Joseph Henry, with great difficulty he went to see it, at a sacrifice purchased it, and from the dismantling of it, constructed a larger one using the silk from his wife's wedding dress as an insulator between the conductors. After much experimentation he finally obtained rotational motion, and later he built a larger motor, the description of which in his memoirs showed his wonderful understanding of the practical considerations involved. United States Patent No. 132 "Improvement in Propelling Machinery by Magnetism and Electromagnetism" was issued to Thomas Davenport, February 27, 1837. This was the first electric-motor patent. And yet Thomas Davenport died penniless and broken-hearted.

The author of the paper made a plea for the definite recognition of Thomas Davenport, yet I venture that the recognition of Thomas Davenport will continue to be found entwined in all of the myriads of contributions by thousands of engineers and scientists which have resulted in bringing forth the millions of electric motors produced each year in our country for service throughout industry, on the farm, and in the home.

And so it is in every avenue of engineering contribution. The recognition of each engineer is to be found in his day-to-day achievements and in those of his associates. And, with proper perspective of the usefulness of the contribution, the satisfaction can be great and the recognition substantial. But nothing is quite so exhilarating as to have the contribution recognized individually.

We also carry in this issue of the REVIEW reprint of an AIEE First-Prize Paper—"Noise Evaluation of Fluorescent Lamp Ballasts," by Messrs. C. P. Hayes and H. R. Gould. Through their contributions beyond the usual, recognition has been brought to Pat Hayes and Herbert Gould by their fellow engineers. This is true recognition.

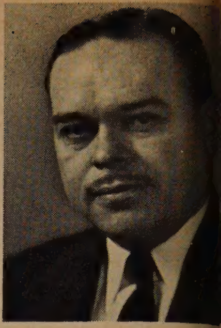
And so in all the Robert Domes, and the Morris Liebmanns, and the Thomas Davenports, and the Pat Hayes, and the Herbert Goulds, we have the engineering profession at work, with recognition in its noblest concepts to all who serve. The immediate audience may not be large but the contributions cover the world.

EVERETT S. LEE

SPECTRUM UTILIZATION IN COLOR TELEVISION

With the available spectrum, a comparatively large number of ways to transmit color-television pictures are possible. These require careful study in choice of system giving best promise

▨ RED
▤ GREEN
▩ BLUE



R. B. Dom

By R. B. DOME
Receiver Division, Electronics Department
General Electric Company, Syracuse, New York

The 6-Mc television channel, now standard in the United States for monochrome or black-and-white television transmissions, may be used in a number of ways for color-television transmissions. It is the purpose of this article to describe some of these ways.

There are in general, for color television, three sets of data to be transmitted instead of the single set for monochrome. The three data may correspond to brightness, hue, and saturation, or to three proper primary colors, or to some linear transformations of the latter.

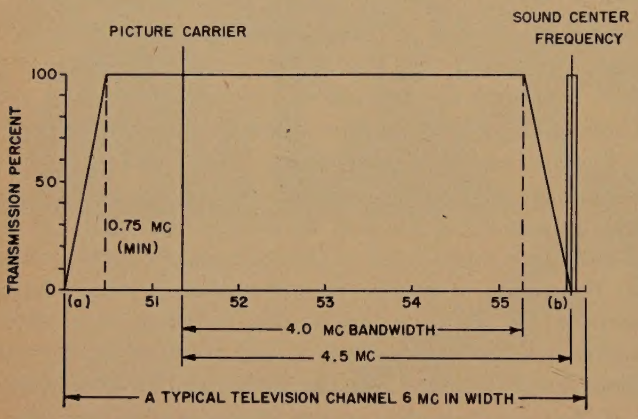


Fig. 1. U. S. standard television channel for monochrome transmission
(*a*). Transmission at lower edge of channel not greater than 0.1 percent
(*b*). Transmission of picture side band at sound carrier not greater than 0.1 percent

If each set of data were transmitted over separate 4-Mc channels, a total bandwidth of at least 12 Mc would be required. Such a transmission method would not fit in too well with the present VHF channel allocation plan. It would also cut in half the number of new channels which would be made available in any additional portion of the radio frequency spectrum opened up for television broadcasting. It is highly desirable, therefore, to see what can be done to utilize to best advantage the present 6-Mc channel for packaging color television signals.

Fig. 1 shows the present channel utilization in black-and-white transmission with the picture carrier located 1.25 Mc above the lower edge of the channel and the sound carrier located 0.25 Mc below the upper edge of the channel. When due allowance is made for a guard band for sound carrier rejection circuits in the picture channel in a television receiver, an upper vi frequency limit of 4 Mc is about the maximum that c be made available in a practical receiver. A sim calculation based on this bandwidth and on a fra rate of 30 frames per second shows that, neglecti blanking intervals, the number of picture eleme making up the structure of the picture is 267,000. T may be used as a yardstick in determining the stru tural quality of pictures portrayed by any of the seve color-television systems to be considered here.

The multiple data of the color signals must be mul plexed in some manner, and a careful examinati should be made of any proposed method or system order to determine whether efficient use is being ma of the available spectrum. Use may be made, the fore, of the known techniques of time-division mul plex, of frequency-division multiplex, or of so combination of the two.

Time-division Multiplex

Time-division multiplex methods will first be amined. Since only one set of data is being dealt w at any instant, the time allocated to one set of da before shifting to a second set of data, must be decid upon. One logical switching point is at the beginni of each new field of scanning. Such a system is sho in Fig. 2. A second logical switching point is at t beginning of each new line of scanning. Such a syst

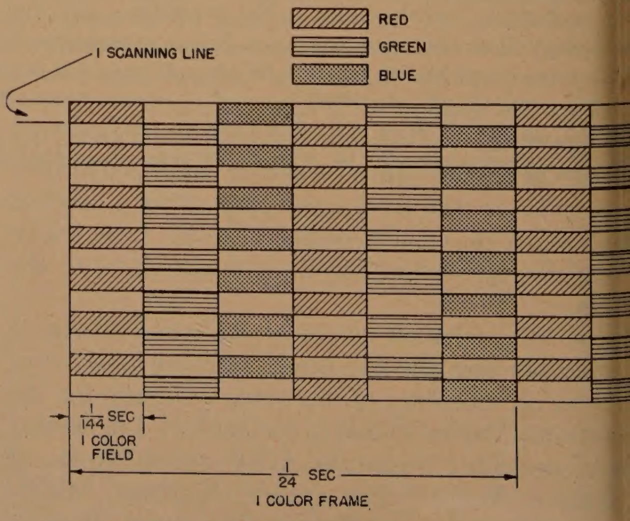


Fig. 2. Field-sequential color-television system

Presented as a paper at the National Convention of the Institute of Radio Engineers, New York, N. Y., March 20, 1951.—Editor.

wn in Fig. 3. A third switching interval may be ne small subdivision of a line. Such a system is n in Fig. 4. These three methods of time-division plex color television may be recognized by their familiar names of (1) Field-sequential, (2) Line-ntial, and (3) Dot-sequential, color-television ns.

e first two of these time-division systems—namely, eld- and line-sequential systems—can provide the quality of picture resolution obtainable in mono- ne providing the field rate is maintained the same monochrome, namely, 60 fields per second. How- if this is done, it will be found that flicker is a em because it takes three times as many fields to lete a color cycle. To reduce flicker, it is necessary crease the field rate; but when this is done, the er of picture elements for structural detail is spondingly reduced so that the resolution becomes ded as compared to present-day monochrome.

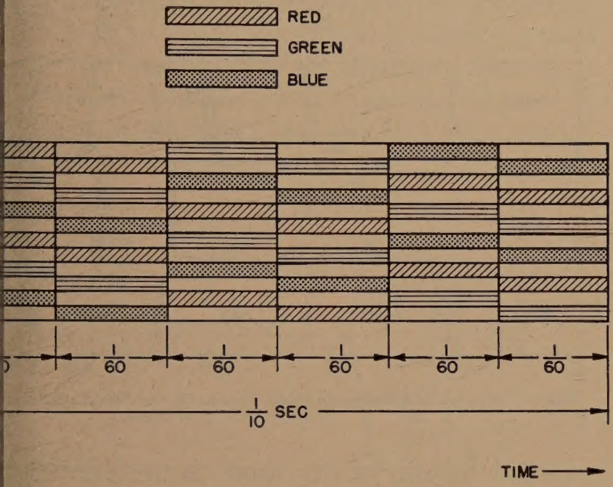


Fig. 3. Line-sequential color-television system

e third system, dot-sequential, when accomplished e combination of sampling and the employment ixed highs, offers advantages. The mixed-highs iple is that of combining the higher video fre- ies associated with each individual color signal dition and displaying this signal as shades of gray. bandwidth gained by employing this principle is derable when it is realized that the saving amounts o of the higher portions of the three video fre- y bands. Thus, if the mixed highs include fre- ies from 2 Mc to 4 Mc, a saving of 4 Mc is ned over a fully simultaneous system. Since a fully taneous system would require three 4-Mc bands, Mc, the bandwidth is at once reduced to 8 Mc. sampling of low frequencies when accomplished in ontal interlace form saves an additional 4 Mc, so the entire signal can be packed into a single 4-Mc

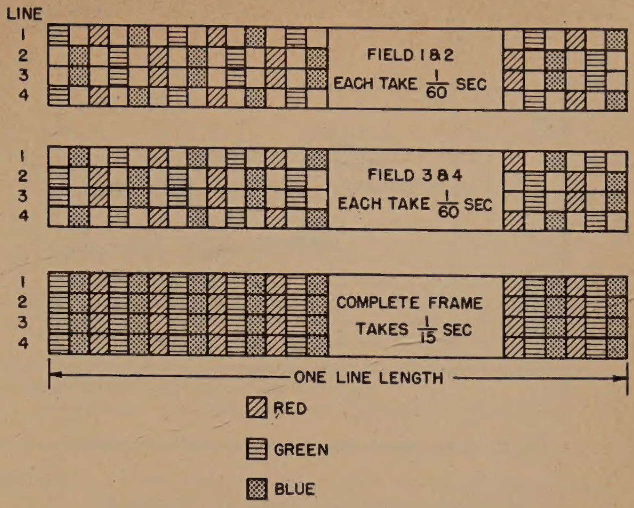


Fig. 4. Dot-sequential color-television system

ency-division Multiplex

e second method of multiplexing is frequency-on multiplex. An obvious way to achieve this is to e the 4-Mc channel into three parts as shown in Fig. 5. The green component of the image may be carried as direct modulation of the picture carrier while the red and blue components may be carried as modulation on two subcarriers. When no overlapping is employed, the theoretical maximum bandwidth per color (assuming equal bandwidths for each color) is 1.33 Mc, so that a considerable reduction in resolution results. When, however, the subcarriers are chosen to be frequencies of the less-visible type—that is, frequencies corresponding to odd multiples of half the line scanning frequency—overlapping may be employed with the result that resolution practically equal to monochrome may be realized. This last system may be recognized as that which has been named "Frequency Interlace." Fig. 6 shows how this has been done in an actual investigation of this system.

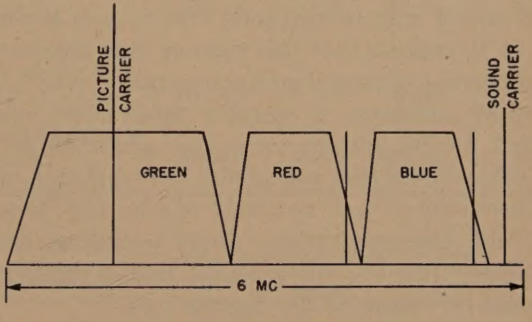


Fig. 5. Simultaneous system employing frequency-division multiplex with no overlap

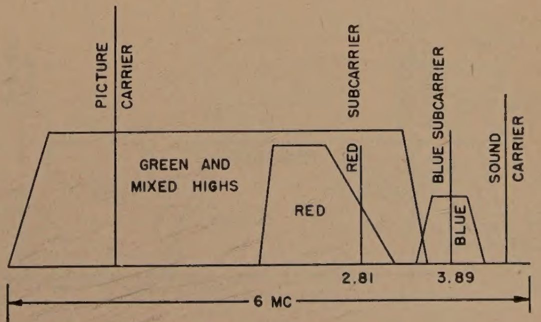


Fig. 6. Spectrum of frequency-interlace system with overlapping mixed highs and red modulated subcarrier

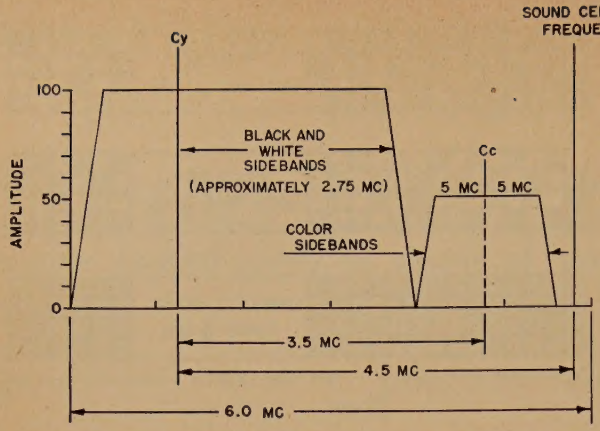


Fig. 7. Color modulation on subcarrier without overlap

The dot structure present in the reproduced picture in color systems employing complete overlap has led to variants of the dot-interlace and frequency-interlace systems in attempts to reduce dot structure. One such system is shown in Fig. 7. In this system, the 4-Mc band is divided so that 0-3 Mc is employed for the transmission of essentially the brightness signal, while two color-identifying signals are carried by modulation on a subcarrier at approximately 3.5 Mc by employing amplitude modulation of an inphase component of the subcarrier for one of the two required color-identifying signals and amplitude modulation of a quadrature component of the subcarrier frequency for the second of the two color-identifying signals. By this system upwards of 75 percent of the resolution of monochrome may be realized.

Another variant of this sytem is now under investigation in which it is probable that vestigial sidebands may be employed for the transmission of the color-identifying signals so that an additional amount of band saving may be realized. This system is shown in Fig. 8. It appears that this system may yield upwards of 85 percent of monochrome resolution, which, for all practical purposes, is scarcely discernible from 100 percent. In this system, the carrier phase of one of the two color-identifying subcarriers is reversed in phase at the beginning of each new field of scanning; that is, on one field, the quadrature carrier would be displaced 90 degrees from the other carrier, but on the next field, it would be displaced 270 degrees.

These last two systems of color television are essentially non-band-sharing simultaneous systems inasmuch as either reduced overlap or very little overlap of co identifying signals into the brightness signal part of spectrum is contemplated. Another approach to separation of color identifying and structural de information so as to avoid the simultaneous use of portion of the available spectrum may be achieved combining frequency-division and time-division te niques. Two such systems have been investigated the laboratories of the General Electric Company. (is known as alternating lows and the other as altern ing highs.

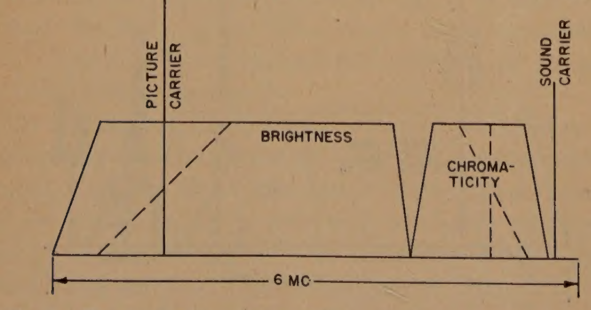


Fig. 8. Non-overlapping system with quadrature component of sub-carrier reversed 180 degrees in phase at end of each field

Combined Techniques

The alternating-highs method may take on a w variety of forms, one of which is shown in Fig. During a first interval of time, such as a field or a l green lows are transmitted as direct modulation of principal picture carrier wave as are also the mi highs of the band 1 Mc to 2.4 Mc. Red lows are car as modulation of a subcarrier and occupy the 2.4 to 3.6 Mc position in the spectrum. Blue lows modu a second subcarrier in the 3.6-Mc to 4.2-Mc posit Care is taken to see that no red or blue sidebands o lap into adjoining parts of the frequency spectr During a second interval of time, the green lows that portion of the mixed highs previously omit namely, from 2.4 Mc to 3.6 Mc, are employed as di modulation of the principal picture carrier frequen while red lows modulate a new subcarrier so chosen t this subcarrier and its sidebands occupy the clea channel from 1.2 Mc to 2.4 Mc. The blue lows occ the same channel as before. It is clear that this sys thus provides for the continuous flow of low-freque color information for all three primaries, but prov for a discontinuous or sequential flow of mixed-h information. By this arrangement cleared channels h been provided for all color information so that the c of each channel may be well filtered to remove traces of dot structure without fear of generating sp ious cross-talk signals between color information mixed highs. A disadvantage of this system is that some lines certain kinds of high-frequency informa will be lacking, although it may be possible by emp

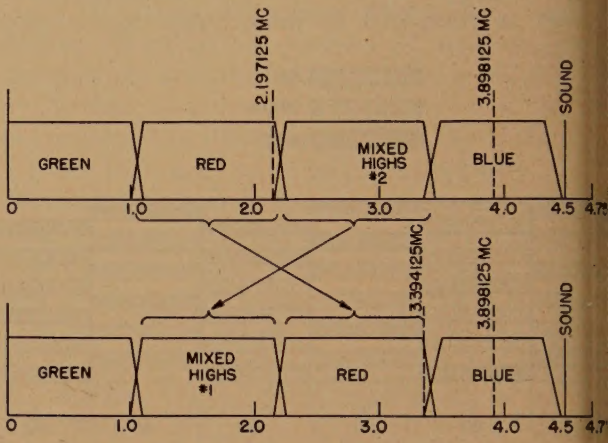
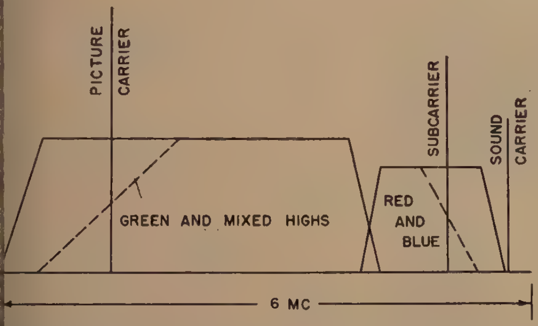


Fig. 9. Spectra of alternating-highs system for the two distinct interv

versing sequences to collect *all* high-frequency
if four fields are employed in a complete cycle.
second of the combination simultaneous and se-
ial systems is the alternating-lows method. This
d is based upon the precept that since the eye is
ute for red or blue images than for green images,
ate color information may be produced by pro-
green lows and mixed highs on every line in the
e but limiting the flow of red and blue low-
ncy components so that, for instance, red lows
ansmitted for an interval of two lines followed by
ows transmitted for one line. This cycle of al-
ing red and blue lows is repeated continuously;
nce 3 is divisible into 525 without a remainder, a
awling pattern in these colors is obtained. At the
er, the coarser line structure of the red and blue
nents may be taken care of on the tube or tubes
display these colors by defocussing the cathode-
ots or by employing very high frequency spot
e in the vertical direction to give soft pictures in
d blue. The green display is kept sharply focused
vide high resolution in the customary manner.
available frequency spectrum may be used in
l ways to transmit color pictures when the al-
ing-lows principle is used. One method closely



). Spectrum of alternating-lows with subcarrier employing vestig-
eband transmission

o that employed in some of the systems previously
ered is shown in Fig. 10. A subcarrier in the 3.5-
4.0-Mc range is employed to carry the red and
low video frequencies alternately. Vestigial-
nd transmission may be employed to conserve
spectrum space for mixed highs.
ther method of utilizing the available spectrum
wn in Fig. 11. No subcarriers are employed with
ethod. Since only two data are being dealt with
y one time, namely, green and red, or, at a later
green and blue, it is possible to amplitude-modu-
e principal picture carrier by the green and mixed-
signals, and to simultaneously modulate a quadra-
omponent of the principal picture carrier by the
blue video signals to separately transmit such
Alternatively, the red and blue signals may be
yed to frequency- or phase-modulate the carrier
instead of employing a quadrature carrier com-
t. A transmitter block diagram of the latter
d is shown in Fig. 12. A receiver block diagram
e phase modulation method is shown in Fig. 13.

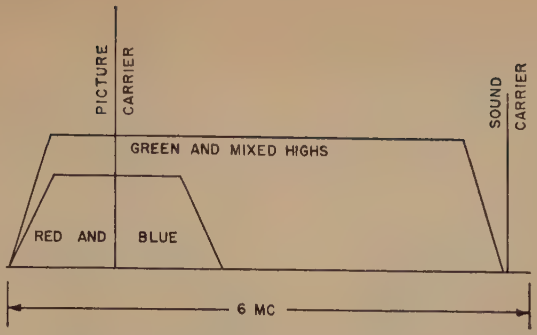


Fig. 11. Spectrum of alternating-lows with quadrature modulation of principal carrier wave by red and blue lows

TABLE I: SUMMARY OF UTILIZATION OF AVAILABLE PICTURE ELEMENTS IN COLOR-TELEVISION SYSTEMS

System	Detail Elements	Color Elements	Total Elements	Percentage Color to Total
Monochrome	267,000	0	267,000	0
Field-sequential (144 Fields/Sec)	111,000	222,000	333,000	67
Line-sequential (60 Fields/Sec)	267,000	533,000	800,000	67
Dot-sequential (overlapping)	267,000	133,000	400,000	33
Frequency Interlace (overlapping)	267,000	87,000	353,000	25
Alternating-highs (non-overlapping)	186,000	60,000	246,700	24.3
Dot-sequential (non-overlapping) color 0.5 Mc, detail 3.0 Mc	200,000	67,000	267,000	25
Alternating-lows with 4-Mc subcarrier and 3.5-Mc detail	233,000	33,000	267,000	12.5
Alternating-lows with 3-Mc detail and 4-Mc subcarrier	200,000	67,000	267,000	25
Alternating-lows with no subcarrier	267,000	50,000	317,000	15.8

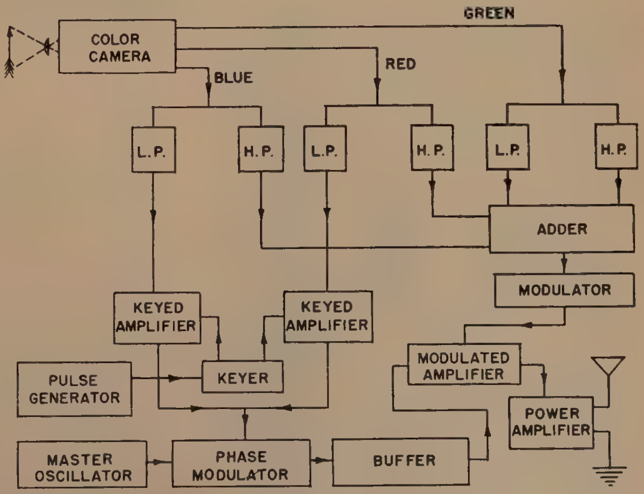


Fig. 12. Block diagram of single-carrier alternating-lows transmitter employing phase modulation for red and blue lows and simultaneous amplitude modulation for green lows and mixed highs

Referring once again to FIG. 11, some advantages of this system will become evident. For one thing, an additional 0.75 Mc of frequency spectrum is opened up for use for data transmission not separately utilized in the other methods. The spectrum for the transmission of structural detail may thus occupy the entire band from 0 to 4 Mc.

Table I summarizes in chart form, for comparison purposes, numerical values for the number of picture elements devoted to the transmission of structural detail, the number of picture elements devoted to color data, the total number of picture elements, and the percentage of color elements to this total for several of the systems described.

In conclusion, then, it appears that the available spectrum may be used in a comparatively large number of ways to transmit color-television pictures. A careful comparative study of these methods should be conducted, taking into consideration such factors as flicker, crawl, dot structure, liability to interference, liability to multipath transmission effects, color fidelity, compatibility, and, last but not least, rece complexity and cost, before deciding which systen systems offer the greatest promise.

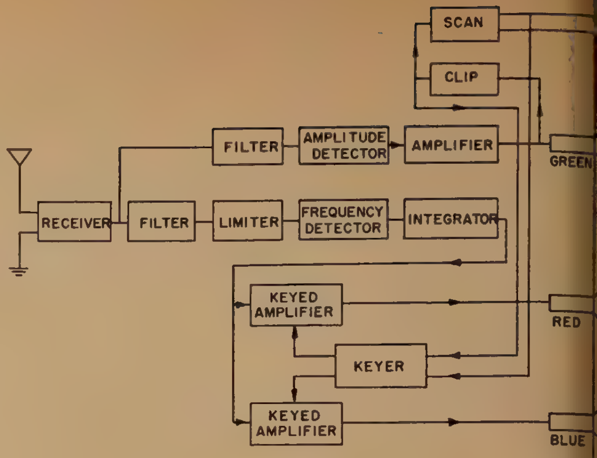


Fig. 13. Block diagram of receiver for the single-frequency ph modulation alternating-lows color system

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HIGH LIGHTS AND SIDE LIGHTS

Steering a Ship by Remote Control

New steering equipment, designed to provide completely automatic steering in addition to portable manual electric steering, has been developed for the U. S. Navy. The new unit will be installed on a vessel currently under construction.

An important feature of the new control is an instantaneous override which permits the helmsman to take control away from the automatic pilot to initiate evasive action or avoid collision. The new ship also has a remodeled pilot house console that features red internal illumination designed to eliminate glare from the dials. In addition magnetic, rather than electronic, amplifiers are used throughout the unit.

Automatic steering console

Portable steering unit in operation

The portable steering equipment is a remote-control box that enables the vessel to be steered from various points about the ship. This secondary control station is intended primarily for use in case of battle damage to the pilot house, whereupon the ship would be controlled from selected steering stations provided for such an emergency. The unit is mobile and is supported from shoulder straps or a fixed bracket.

Safe and Sanitary Reclamat of Feed Bags

Disease germs are now being cook death in a new sanitizing operation w saves farmers millions of dollars a and helps stretch this country's avai jute supply.

Burlap feed bags are made safe for r by heating them in special giant known as dielectric high-frequency o Since these bags are durable enoug be used an average of six times, cost thus cut to about one-fifth and there i drain on the supply of jute—the imp raw material from which burlap is ma available for new bags.

Because of the possibility of a sp of animal and poultry diseases by th of feed bags that have been in po houses or on dairy farms, used bags be freed of any disease germs b again being filled with feed. After ex ments with steam, ultraviolet light, cyanide gas, it was found that he with high-frequency electricity was most practical way to sanitize the Bags in bales of 250 each were conv between electrodes in dielectric ovens the temperature throughout the brought up to 230 F, sufficient to kil desirable disease organisms but not to or otherwise harm the bags.

Two of the largest dielectric ove their type ever built were constru specifically for this purpose. Each is 44 ft long, 9 ft high, 9 ft wide, operates at a frequency of about 13,00 cycles with a total power requireme 120,000 watts per oven.

S TURBINE-CENTRIFUGAL COMPRESSOR STATIONS FOR S-PIPE-LINE PUMPING

Some installation features of El Paso Natural Gas Company's large-scale pipe-line system

By J. F. EICHELMANN and J. S. QUILL

Chief Engineer
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Industrial Engineering Divisions
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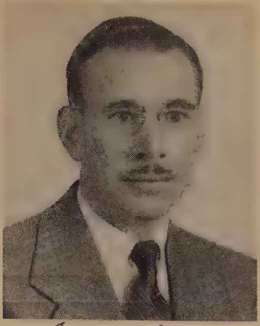
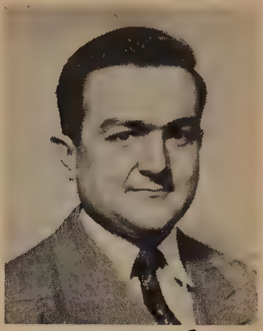
General Electric Company





J F Eichelmann

Joseph S Quill

Mr. Quill received a Charles A. Coffin Award for his outstanding ingenuity, resourcefulness, engineering skill, and imagination, in collaboration with Russel W. Van Kirk, in the original conception of the application of industrial gas turbines to gas-pipeline pumping.

Mr. Van Kirk received a Charles A. Coffin Award for his outstanding ingenuity, resourcefulness, and commercial competence, in collaboration with Joseph S. Quill, in the development of a new market for industrial gas turbines for application to gas-pipeline pumping. Mr. Van Kirk is Manager of the Apparatus Department Sales Office of the General Electric Company at El Paso, Texas.—EDITOR

HE first large-scale installation of gas turbine-lriven centrifugal compressor stations for natural-ipe lines has been undertaken by the El Paso al Gas Company. The gas turbine pumping equip-is being supplied by the General Electric Company. purpose of this paper is to describe the gas ne-centrifugal compressor stations designed for lation in the El Paso Natural Gas System.

n and Gas Flow Conditions

part of the pipe-line system under consideration xtends from the West Texas-New Mexico border California border and consists of a 26- and a 30-pe in parallel as shown in FIG. 1.

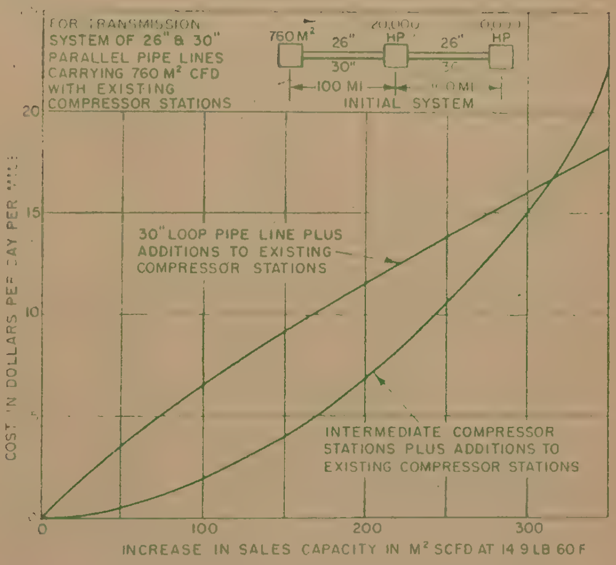
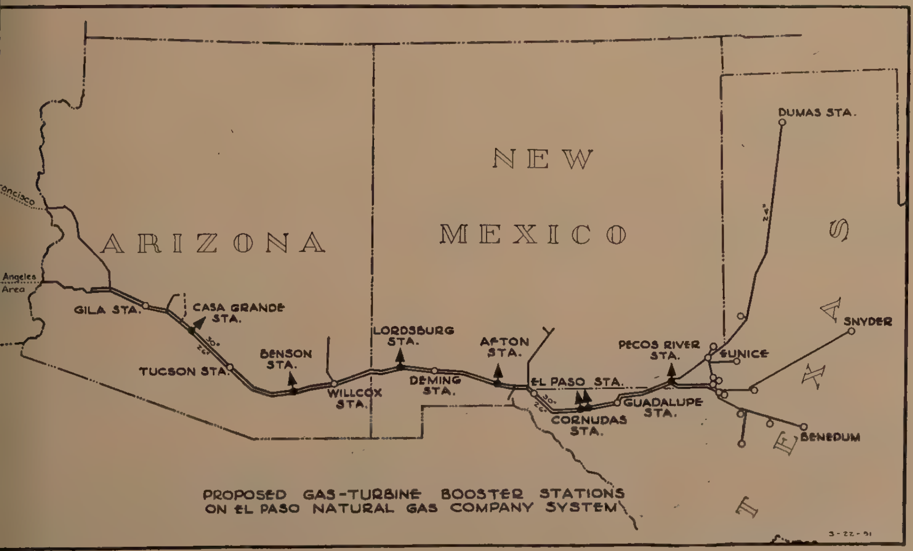


Fig. 2. Relative cost of increasing sales capacity by looping the line and by intermediate compressor stations

Parallel 26- and 30-in. pipes extend from West Texas through New and Arizona



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nted as a paper at the Spring Meeting of the Natural Gas Dept. of the n Gas Association, held at Dallas, Texas, May 7-8, 1951.—EDITOR.

The flow in this line at the present time is about 700 million standard cubic feet per day (M^{2}SCFD*); this is to be increased to approximately 800 M^{2}SCFD in the immediate future, and later to 1100 M^{2}SCFD. The line operates at a maximum pressure of 813 psia.

Cost of Looping** Versus Booster Stations

In order to find out whether it is more economical to install booster stations or to loop the line, a comparison of the two methods was made on a representative 200-mile section of the El Paso system. It was assumed that the line initially carried 760 M^{2}SCFD and had 20,000-hp compressor stations located 100 miles apart. For small increments of flow only part of the line was looped, the length of loop being that required by the flow when a compression ratio of 1.5 is maintained at the compressor stations. The horsepower in the compressor station was increased as required. The results of the comparison, in Fig. 2, show that booster stations are more economical for approximately 300 M^{2}SCFD of additional flow and that looping is less expensive for larger flows.

The decision to install seven 5000-hp gas turbine-driven centrifugal compressor stations for 1952 included provision for twenty-one additional units as the gas flow increases.

Why Gas Turbines Were Selected

The decision to install gas turbine-centrifugal compressor stations was based on the following consideration:

High-efficiency Centrifugal Compressors at Low Compression Ratio

Gas turbine-centrifugal compressors are ideal for booster stations. For example, the 5000-hp booster stations for El Paso are designed for flows ranging from 1200 to 800 M^{2}SCFD and compression ratios from 1.10 to 1.16. At these low compression ratios, centrifugal compressors are considerably more efficient than reciprocating compressors. This results from the fact that the leaving losses of a reciprocating compressor become a significant portion of the useful horsepower. Fig. 3 shows the brake horsepower per million versus compression ratio for both reciprocating and centrifugal compressors. Booster-station horsepower can be reduced by as much as 20 percent at low compression ratios by installing centrifugal compressors.

Less horsepower has to be installed and less fuel gas consumed when the gas is given small boosts in pressure at more frequent intervals. A small pressure boost does not require aftercooling, and this saves on installed cost and maintenance.

TABLE I

TOTAL YEARLY OPERATING COSTS OF GAS TURBINE-CENTRIF AND GAS ENGINE-RECIPROCATING GAS-PIPE-LINE COMPRE STATIONS

	Gas Engine Standard Type	Gas Turbine with Regenerator 80 F
Bhp installed	100,000	91,000
Cost per installed hp	$200	$150
Station cost total	$20,000,000	$13,650,000
Yearly capital costs at 9%	$1,800,000	$1,230,
Yearly operating & maintenance labor cost per hp	$15	$5
Yearly operating & maintenance labor cost	$1,500,000	$455,
Total station fuel consumption, including auxiliaries, cu ft per bhp-hr	9	10
Yearly fuel costs at $0.15 per 1000 cu ft, 1.0 capacity factor	$1,180,000	$1,200,
Total yearly operating costs	$4,480,000	$2,885,

Economical

The basic data for making an economic comparison between reciprocating gas engines and gas turbines are shown in Table I. The values in Table I are those frequently used in the gas-pipe-line industry; if more accurate figures for particular cases are available, th may be inserted and results modified according

For purposes of comparison, a line is assumed to quire 100,000 hp of reciprocating gas turbine compr sors. When the compression ratio of the stations low—say, 1.20, as in a 10,000-hp station for the Paso Natural Gas Company—the reciprocating statio

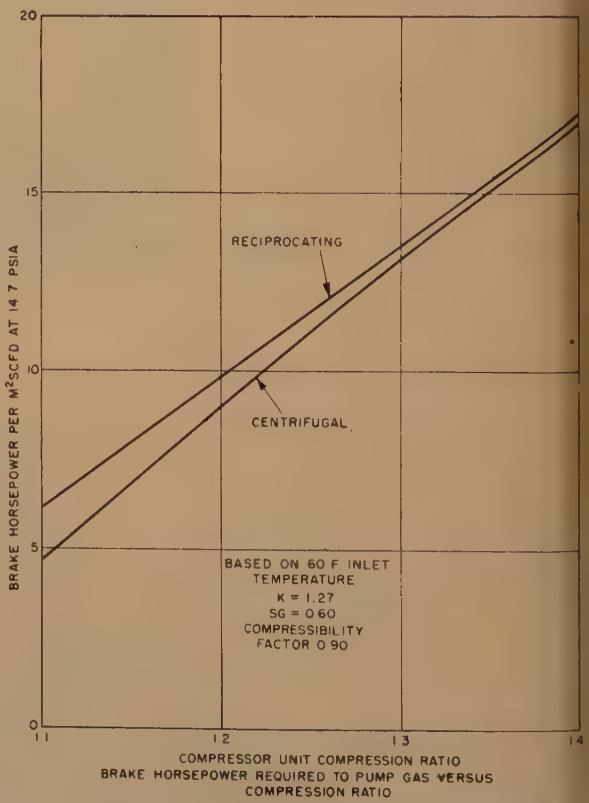


Fig. 3. Brake horsepower required to pump gas vs. compression rat

e approximately 9.8 bhp per million cubic feet, the centrifugal stations require only 9 bhp per n cubic feet for the same pressure boost. Thus, uires 91,000 hp of centrifugal compressors to pump me amount of gas that 100,000 hp of reciprocating essors will pump at the same compression ratio.

---

*A standard cubic foot is taken at 14.9 psia and 60 F.

**To a pipeliner "looping" a line means to install another pipe in parallel with the existing pipe.

results of the economic comparison shown in 4 indicate that with gas engines the total yearly are 4.48 million dollars; with the gas turbines the yearly costs are 2.89 million dollars. The same nt of gas is pumped in either case.

t evaluated, but distinctly in favor of the gas ne, is the 25 percent additional horsepower avail- n the winter, as will be pointed out later.

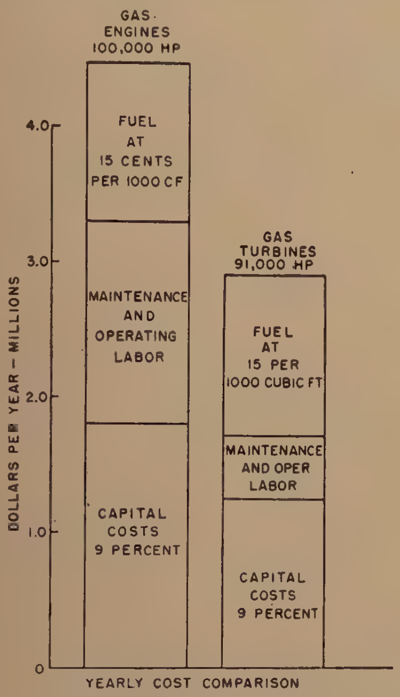


Fig. 4. Economic comparison of gas engines and gas turbines

ater Required

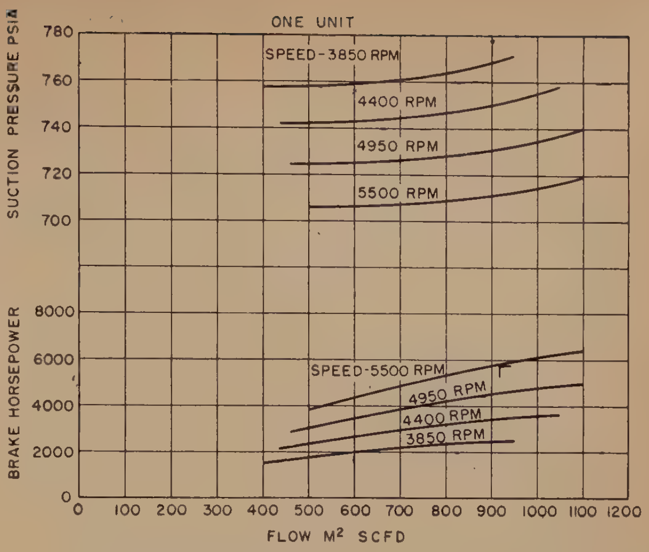
e gas turbine station can be operated in the middle e desert with no cooling water required except to ce very small losses in the recirculating oil cooling system. The heat from the lubricating oil is re- d by air-blown radiators. Where a small quantity ter is available, additional horsepower output can otained by washing and precooling the incoming

ates Its Own Auxiliary Power

e gas turbine pumping unit is a complete self- ined plant and includes a turbine-driven a-c ator. No additional electric power need be pur- d or generated in the station while the gas turbine nning.

ional Horsepower Available in Winter

the winter, when demand for gas is greatest, the urbine will deliver approximately 25 percent more r than its nominal 80 F rating, because ambient eratures are lower. A fundamental characteristic of gas turbines is that they can deliver increasing amounts of power as ambient temperatures decrease. Some surplus power will be available from the gas turbine much of the time, because the average temperature in most locations is below 80 F, the ambient temperature on which its rating is based.



DISCHARGE PRESSURE 813 PSIA GRAVITY 0.669 GAS STANDARD 14.9 PSIA
INLET TEMPERATURE 60 F "K" 1.27 60 F

Fig. 5. Expected compressor performance in the El Paso-Pecos River station

Flexibility

Its adjustable speed characteristics can take care of the variable flow and pressure-ratio requirements.

Low Lubricating-oil Consumption

The lubricating-oil consumption requirement of a 5000-hp gas turbine station is estimated to be less than twelve gallons per month.

Unattended Stations

The gas turbine is a simple rotating machine and completely automatic in its starting and stopping. The unit is protected against excessive high temperature, low lubricating-oil pressure, overspeed, excessive vibration, etc.

These inherent features require minimum attendance. It is expected that at some time in the future the automatic stations will be operated by the dispatcher located in El Paso. Provisions are made so that the units can be started and stopped, speed adjusted, and pressures read from the remote location over the future microwave communication system.

Centrifugal Compressors

Centrifugal compressors manufactured by Clark Brothers, Inc., DeLaval Steam Turbine Company, and Ingersoll Rand Company will be installed in these stations. The centrifugal compressors, directly driven by the gas turbine output shaft, are single-stage and approximately 82 percent efficient at rated load. A typical centrifugal compressor characteristic is shown in Fig. 5. All of the casings, with impeller changes, are designed to take a future flow of 1100 M²SCFD.

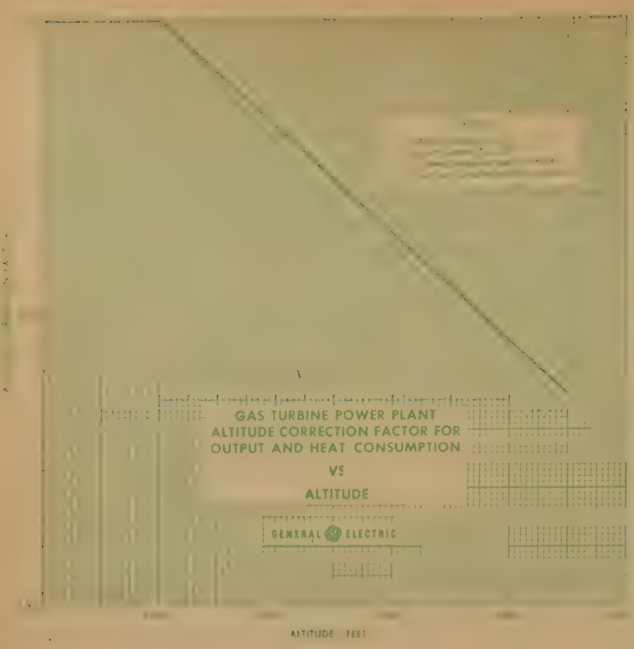


Fig. 6. Chart of altitude correction factor

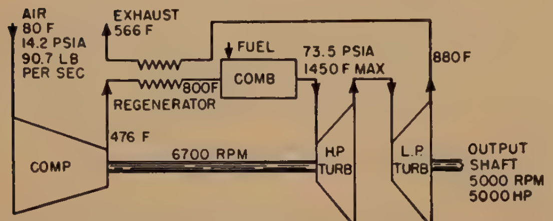


Fig. 7. Schematic diagram of a 3500-kw 5000-hp regenerative-cycle gas turbine

Description of the Gas Turbine Selected

The rating of the gas turbine to be installed on the El Paso Natural Gas system is 5000 hp, 5000 rpm, 80 F, 1000 ft altitude, and 25 percent thermal efficiency based on lower heating value of the fuel. The altitude correction factor curve is shown in Fig. 6. The flow diagram of the pipe-line gas turbine is shown on Fig. 7.

The special features that make this turbine particularly desirable for pipe-line pumping are:

(1). The turbine portion is composed of two sections, each driving a separate shaft—one for the axial-flow air compressor, the other to drive the load. With this arrangement, constant horsepower output over a wide range of speed on the load compressor can be obtained by running the axial-flow air-compressor shaft at different speeds.

(2). A regenerator has been added to recover
utilize heat that would otherwise be wasted in the
haust, thus resulting in a higher thermal efficien
Fig. 8 shows the operating limits of horsepower
function of speed for various ambient temperatu
For a given ambient temperature, it is possible
operate at any load up to the limit shown on the cu
over the speed range from 2000 to 5500 rpm.

Since the horsepower characteristic of the gas turb
is very flat in the vicinity of 5000 hp (the rating of
turbine), the compressor can be selected to deli
approximately 5000 hp at any speed ranging from, s
4000 to 5500 rpm. A compressor selected to deve
5000 hp at 4500 rpm can be speeded up in the winter
absorb 6300 hp available from the gas turbine at 4
ambient.

The 80 F fuel consumption at various loads
included in Fig. 8. Full-load fuel consumption is
cubic feet per brake horsepower hour of fuel having
lower heating value of 1020 Btu per cu ft. The eff
of ambient on load limit is also shown in Fig. 8. T

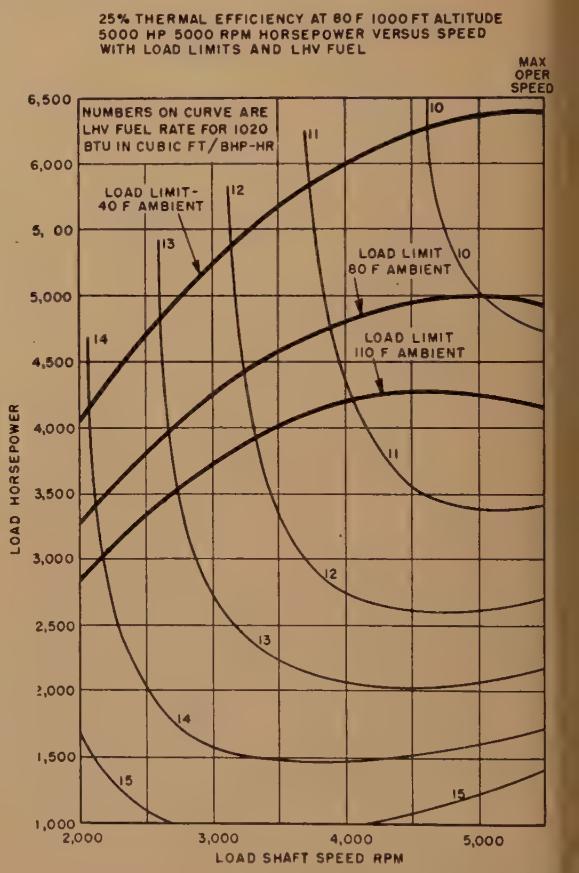


Fig. 8. Characteristics of a 500
two-shaft gas turbine with regener

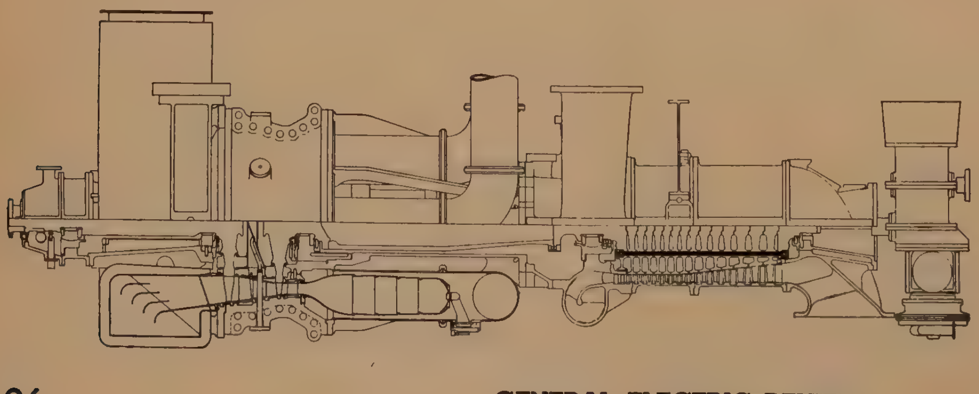
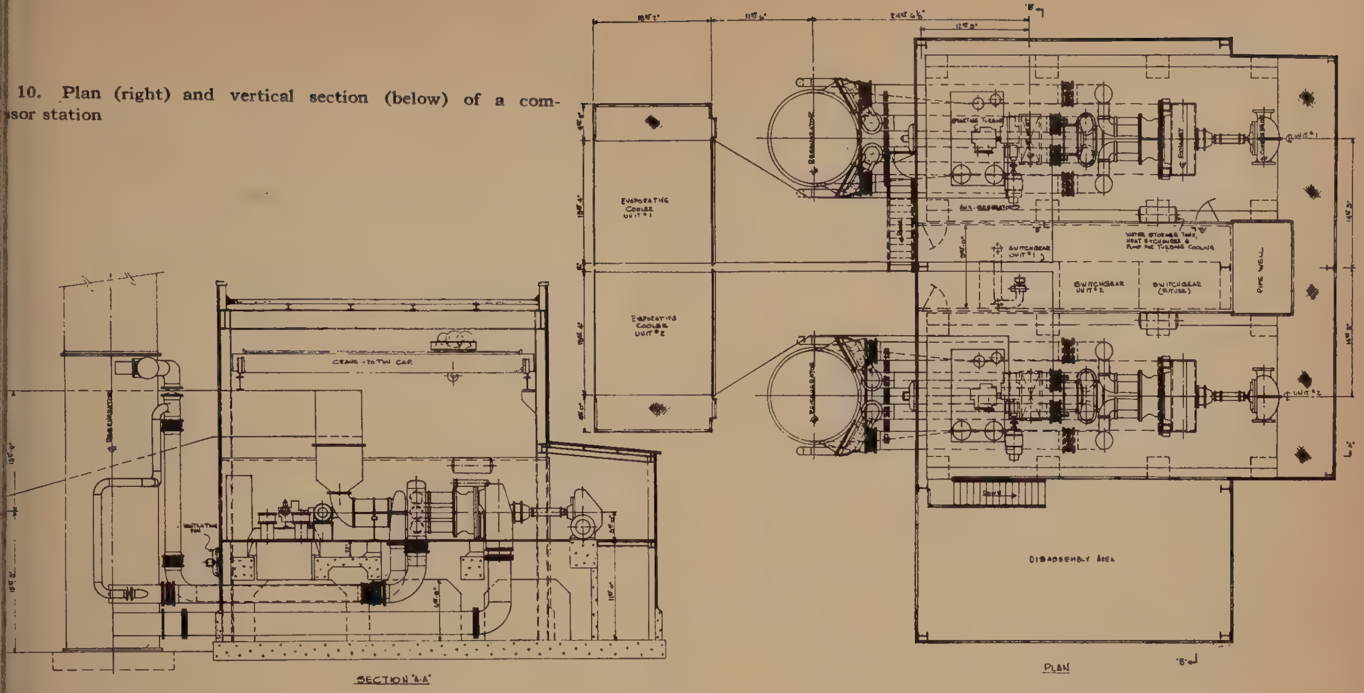


Fig. 9. Longitudinal section of
5000-hp gas turbine power plant
the regenerator

10. Plan (right) and vertical section (below) of a com-
ssor station



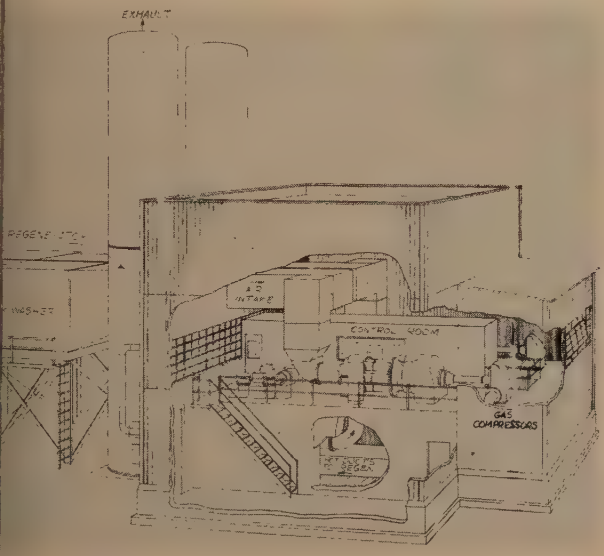


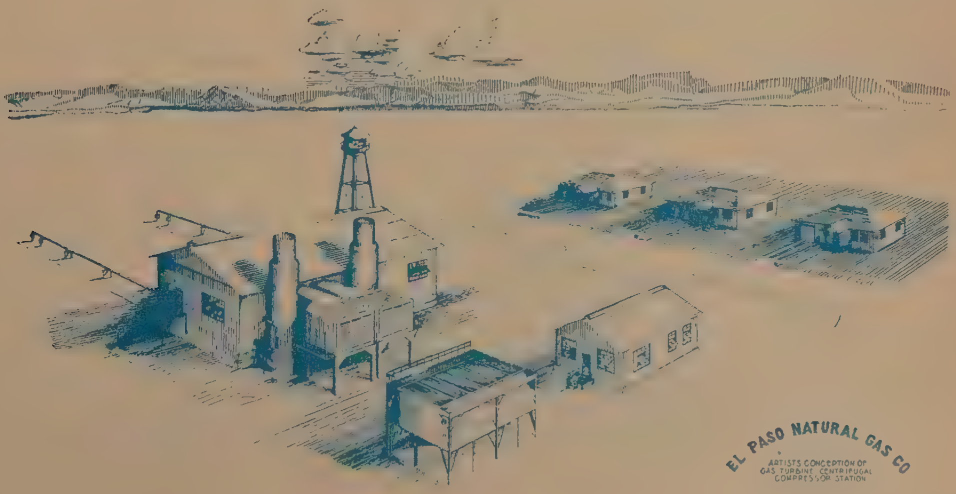
Fig. 11. Cutaway view of a compressor station

turbine develops its full rating, 5000 hp, at 80 F ambient; and when the ambient is 40 F the unit will develop approximately 6300 hp, or 25 percent above rated load.

A cross section of the turbine is shown in FIG. 9. The ducts going to and returning from the heat exchanger are shown, although the heat exchanger itself is not. The fact that the load shaft is independent does not make much difference in exterior appearance, since both turbine wheels are enclosed in the same housing.

Description of the Station

The plan and cross section of a two-unit 10,000-hp gas turbine-compressor station are shown in FIG. 10. The building is relatively small in size—50 ft×50 ft×40 ft, or approximately 10 cubic feet per horsepower. The disassembly area will permit bringing in a complete power plant and putting it on location with a crane, thus saving installing time and expense. The light weight of the power plant—45,000 lb—makes this possible. FIG. 11 shows a perspective sketch of the station proper, and FIG. 12 shows a general view of the


EL PASO NATURAL GAS CO
ARTISTS CONCEPTION OF GAS TURBINE CENTRIFUGAL COMPRESSOR STATION

. Sketch of the complete instal-
of a two-unit gas-pipe-line station

complete installation. Four-unit stations are contemplated for the future expansion.

The regenerator is a shell and straight-tube type of heat exchanger, the shell being the high-pressure side. The shell is fabricated from boiler plates, and the tubes are rolled and butt-welded from carbon steel material. The regenerator which forms the base of the exhaust stack is 10 ft in diameter, 33 ft long, and contains approximately 5000 1¼-in. OD tubes.

The evaporative cooler air filter is dual-purpose equipment. Its primary function is to lower the temperature of the intake air during high-ambient operation. For example, on a 100 F day at 20-percent relative humidity, the effective ambient is approximately 69 deg wet-bulb temperature for that day. Under these conditions, the summertime output can be increased by more than 15 percent by evaporative cooling. Two sets of sprays are located in the evaporative cooler, one for evaporation and one for continuous washdown of the filter equipment. A tank is built into the base of the equipment for water storage. Only about 15 gpm are required for such operation.

Auxiliary Power

Four sources of auxiliary power are provided in the station. A 150-lb air supply system is used for instruments and miscellaneous valve operation. A 125-volt d-c station battery is used for control power, ignition, and, through a motor-generator set, for emergency lights and for supplying lubricating-oil pressure during starting and stopping. A 75-kw generator, gear-driven from the gas turbine, provides the auxiliary power for all motors in the station during the operation of the gas turbine. A small gas-engine-driven generator provides a-c power in the station for charging the station battery when the gas turbines are shut down.

The major auxiliaries consist of the following:

Gas Turbine Auxiliaries

One 1.5-hp a-c cooling-water pump (for cooling of gas turbine parts)
Two 3-hp d-c lubricating-oil pumps (used during starting and stopping only)
One 1-hp d-c cooling-water pump (stand-by for above. Used during starting and stopping)

Centrifugal Compressor Auxiliaries

One 7.5-hp a-c seal-oil pump (stand-by to shaft-driven pump)

Evaporative Cooler

One 10-hp a-c spray pump for evaporation
One 15-hp a-c water pump for filter wash

Station Auxiliaries

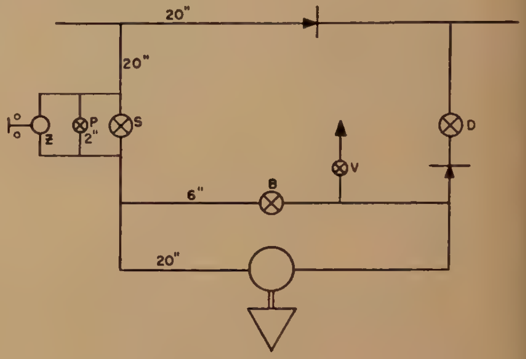
One 7½-hp a-c water pump for lubricating-oil coolers
One 15-hp a-c cooler pump for fin-fan blowers
One 7½-hp air compressor
Two 2-hp a-c vent fans for turbine room
One feeder for 15-gpm water-supply system

The water requirements of the station are relati small, because it is expected that aftercooling of pipe-line gas will not be required.

Lubricating-oil System

A common lubricating-oil system is used for both gas turbine and the centrifugal compressor. The supply consists of an 850-gal tank located beneath starting turbine. The main turbine lubricating- pump is gear-driven from the turbine and is supp mented by two d-c pumps, for use during starting a stopping.

The centrifugal compressor high-pressure seal- pump is gear-driven from the compressor; an a-c hi pressure stand-by seal-oil pump is also provided.



1. WITH STATION DOWN
    OPEN B,V
    CLOSED P,S,D
2. STARTING SEQUENCE
    (a) B CLOSES AT 10 PERCENT N
    (b) P OPENS WHEN GAS TURBINE FIRES
    (c) V CLOSES 5 SEC AFTER TURBINE FIRES
    (d) S AND D OPEN WHEN Z INDICATES ZERO DIFF PRESS.
3. STOPPING SEQUENCE
    (a) B OPENS WHEN STOPPING SIGNAL IS GIVEN
    (b) S,D,P CLOSE A FEW SECONDS LATER
    (c) V OPENS WHEN LOAD SHAFT COASTS TO 25 PERCENT N

Fig. 13. Diagram of the valving sequence

Temperature of the lubricating oil is maintained 130 F by circulating 225 gpm of 115 F cooling water the oil coolers, with a five-degree rise in the cooli water. The tube material is arsenical admiralty met and two oil coolers are used, one of which is a spar With a recirculating water system between the coole and the radiators, the design is conservative.

Starting

The gas turbine is started by means of a mechanica drive turbine operating from gas line pressure. It is n expected that frequent starting will be necessary, a the 35,000 cu ft of gas used for each start is justified the increased reliability of this starting means over a other method, for isolated installations. The expand gas is exhausted to atmosphere.

Starting is completely automatic. When the mast start switch is placed in the ON position, the d lubricating-oil and cooling-water pumps are starte When the d-c pumps have filled the compressor ov head seal-oil tank, the starting turbine brings the g turbine up to 10-percent speed, where the turbi ı is purged for three minutes. The turbine is now nd accelerated to 60-percent idling speed, where : auxiliaries are started and the starting sequence pleted.

ng

en the stopping signal is given the fuel is stopped, generator is by-passed, and the main suction and rge gas valves are closed. The load turbine shaft ected to come to rest in approximately 6 to 8 es, and the high-pressure turbine shaft will come in approximately 15 minutes. To keep the bear- ool, provisions are included to run the d-c pumps proximately 30 minutes after the unit comes to Restarting can take place at any time after both come to rest.

l

gas turbine will usually be so operated that the is varied to maintain compressor discharge pressure. Maximum exhaust temperature and maximum speed are over-riding controls. A selector switch is provided so that the unit can be placed on manual speed control if desired. Where more than one turbine is installed in a station, it is expected that only one unit will be operated on automatic discharge pressure control, with the remaining units on manual speed control. The control system is flexible so that, as experience indicates, the actual operation can be changed.

Station Valving

A valving diagram of an individual centrifugal compressor is shown in FIG. 13. The simplicity of the station piping is possible because the complete flow of the line goes through each centrifugal compressor and for a multiple-unit station the compressors are placed in series. The main gas valves are operated from gas line pressure and are electrically pilot-operated, with extreme travel-limit switches to provide for automatic operation of the station.

HTS AND SIDE LIGHTS

Ductile Magnet

obalt-platinum magnet, which, in zes, is described as the world's most ul permanent magnet, has been de- l in the Research Laboratory at the

nt commercial use of the new : will be limited, however, not only ernment restrictions on the use of but by prohibitive expense of the mounts of platinum used in the t is not expected to replace pres- ised magnetic alloys, such as the oy* alnico magnets, but rather to ew fields of use for which existing s are not suitable.

pared with alnico-5 magnets, gen- ated as the most powerful in com- l use, the new magnet is less power- large sizes but more powerful in zes. Laboratory experiments with a cobalt-platinum magnet about the size of an eraser on a led pencil and a similar-sized alnico-5 magnet show the new magnet to have lifting power 24 times greater than that of alnico-5 and about eight times more resistance to demagnetization.

Cobalt-platinum magnet is expected to open new fields of use for permanent magnets

Magnets are limited in size by their tendency to demagnetize themselves when opposite poles, at the ends of the magnet, are brought too close together. The new magnet has a strong resistance to this tendency. This resistance to demagnetization, called coercive force, enables the cobalt-platinum magnet to be more efficient in smaller sizes than any permanent magnet now in commercial use.

Other advantages of the material are its ductility, or ability to be drawn into wire or thin sheets, and its comparative ease of machining. Alnico magnets can be machined only with great difficulty.

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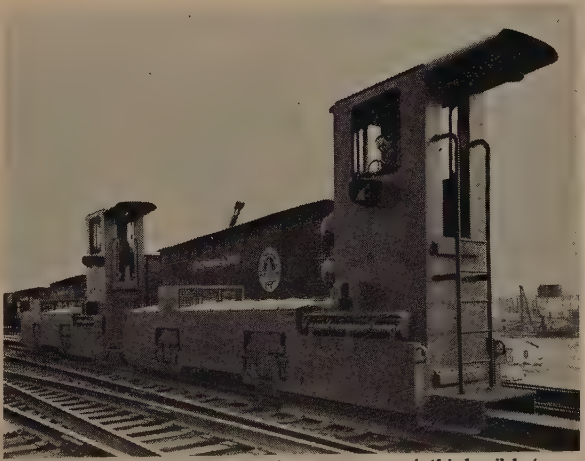
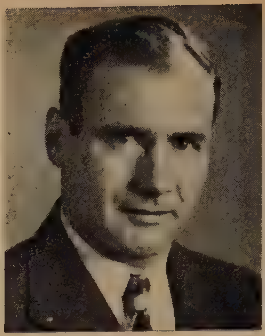
*Reg. trade mark.

Side-pushing Locomotive



This odd-shaped vehicle is a locomotive which pushes from the side instead of the usual way. By operating on a narrow-gage track between two sets of standard tracks, the side pusher eliminates much of the shuttling required with standard switcher locomotives. Pincer-shaped arms (on both sides of the cab directly beneath operator) spring out and hook onto the freight cars, enabling the locomotive to move two lines of freight cars simultaneously when necessary. A third rail between the narrow-gage tracks provides electricity to power the pusher's two electric motors

GENERAL ELECTRIC THRUST BEARINGS: 1931-19



E.P. Smoo

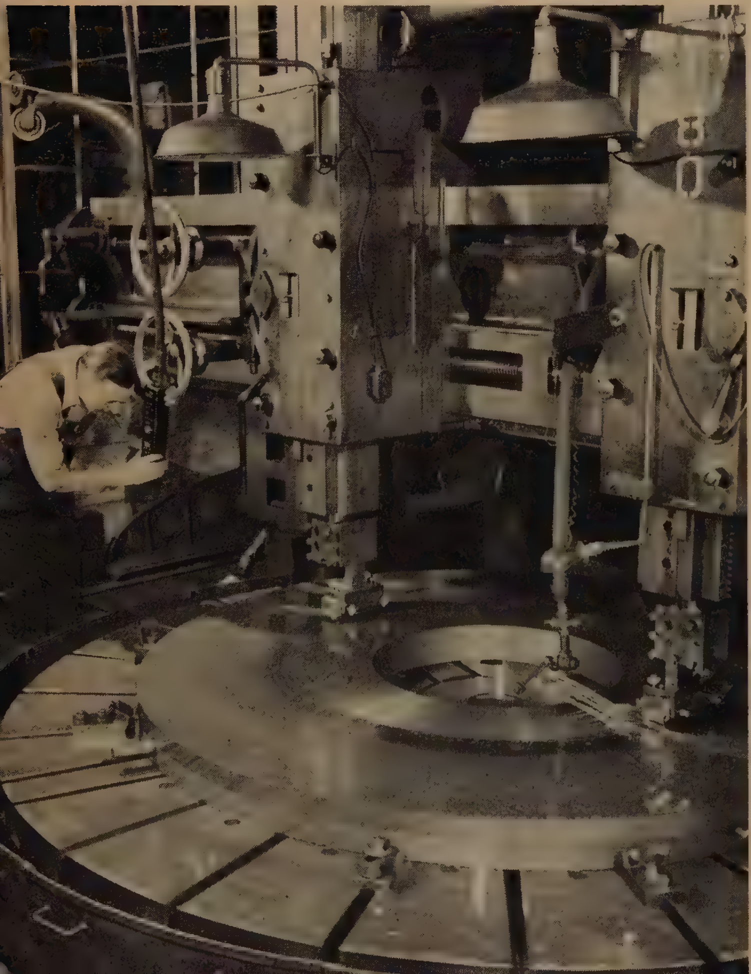
This historical sketch relating to the development and installation of some of the larger thrust bearings now in use describes pertinent technical aspects of bearing design

By W. S. MOODY
Los Angeles Office

and E. P. SMOOT
Large Motor & Generator Divisions
General Electric Company

WHILE there have been no radical changes in operating principle of the General Electric thrust bearing since its inception, there has been a continuing evolution through minor refinements and improvements of design details. Results of these refinements since the early 1930's were recently demonstrated at Hoover Dam, with the co-operation of the Department of Water and Power of the City of Los Angeles and the Bureau of Reclamation of the U.S. Department of the Interior, when the latest type of bearing was installed on Unit N-7. This machine is rated 82,500 kva, 180 rpm, and the bearing carries a load of 1,786,000 lb.

Fig. 1. Runner of new thrust bearing for unit N-7 at Hoover Dam being finished on a boring mill in factory at Schenectady



Replacement of N-7 Bearing at Hoover Dam

The decision reached to install the up-to-date beari was the result of a discussion held in Schenectady October 1950 when it was learned that the N-7 u would be shut down early in 1951 for complete inspe tion and for maintenance work on the turbine. A ge eral discussion of the operating record of this particul unit brought out the fact that there had been so thrust bearing troubles on the unit because of warp runner plates. It was agreed that the installation of up-to-date thrust bearing in this unit would undoub edly give interesting and useful data. A bearing w ordered by the Engineers of the City of Los Ange with the understanding that it would be installed a in operation by March 11, 1951—the agreed date th the N-7 unit should be back on the line. This allow just about a normal minimum of manufacturing ti to produce the bearing (Fig. 1) and get it to the pla

But troubles ensued. During the final machine ope tions on the thrust runner a defect turned up in t casting, requiring that it be scrapped and replaced. ' minimize delay, all methods of shipment were inves gated. It was found that the size and weight of t packed thrust runner were such that it could not shipped by air freight, express, or truck. Therefore, t initial decision was to ship it by a Los Angeles car a then back to Hoover Dam. However, it was ultimate determined that, by making arrangements with t National Carloading Company to include the shipme in one of their consignments and provide tracer servi several days could be saved.

After a period of working continuously, the repla ment runner together with the other necessary pa were completed and ready to ship Thursday eveni March 1, and left Albany, New York, by special tra at 1:00 a.m. Friday, March 2. Shortly after leavi Chicago the car in which the bearing was shipped bro down and had to be returned to Chicago, where t shipment was changed to another car. In spite of t delay, however, the car was delivered to Las Vegas Sunday evening, March 11, and the parts required initial assembly were removed from it immediate The remainder of the material was delivered at Hoo Dam Monday morning, March 12.

Happy over initial runs of new G-E thrust bearing in Unit N-7 at Hoover Dam are: (left to right) R. B. McKeeby, G-E, Schenectady; O. A. Gustafson, G-E, San Francisco; A. C. Wingo, City of Los Angeles Department of Water and Power F. A. Latham, City of Los Angeles Department of Water and Power, Hoover Dam; and R. L. Clark, City of Los Angeles

C. W. Keller, G-E Denver Office, who handled the original proposition for Units N-1 and N-2 at Hoover Dam presenting framed copy of photograph to L. N. McClellan, Chief Engineer of the Bureau of Reclamation, under whose direction the original specifications for Hoover Dam generators were issued. Between them stands S. M. Denton, Bureau of Reclamation

A. Latham (at right), Superintendent of Hoover Power Plant
the City of Los Angeles, Department of Water and Power,
sents electric razor to A. J. Dole, mechanic for Department of
ter and Power, as prize for guessing nearest correct time of
val of new bearing for Unit N-7 at Hoover Dam

W. S. Moody (left) and A. C. Wingo (center) report the results of the initial runs of the new G-E bearing on Unit N-7 at Hoover Dam to C. P. Garman, Chief Electrical Engineer and Deputy General Manager of the Department of Water and Power, City of Los Angeles. Mr. Wingo holds spring such as is used under stationary segments of G-E bearing

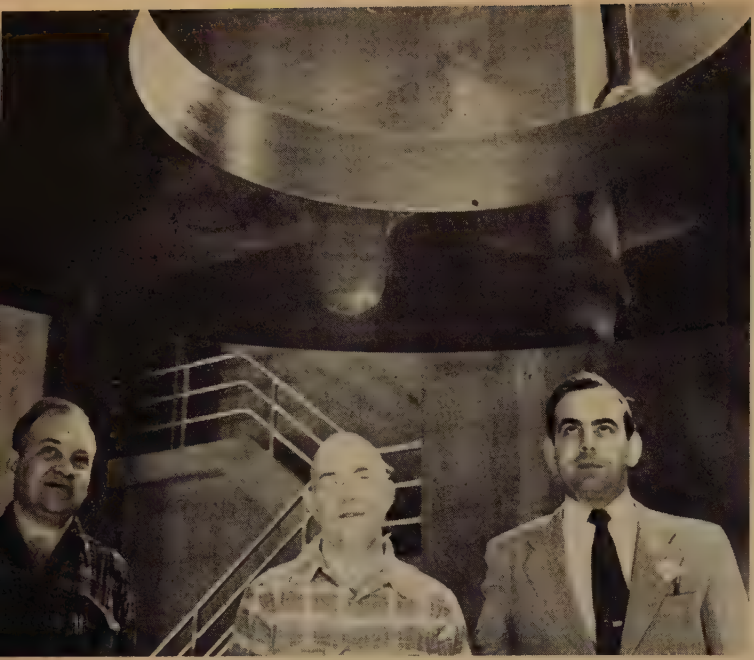


Fig. 2a. Surface of new runner at Hoover Dam after completion of 6 starts. Note reflection of faces in runner surface

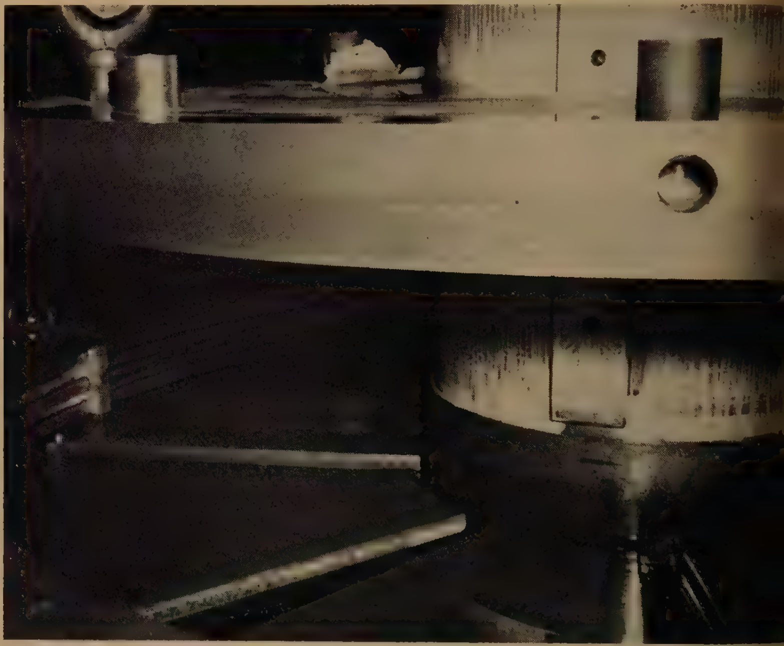


Fig. 2b. Condition of stationary segments of new G-E bearing after initial run at Hoover Dam

In view of the special efforts to speed up the delivery of the thrust bearing and of the interest in these at Hoover Dam, a prize of an electric razor was offered for the person who guessed the nearest correct time of the arrival of the bearing at Hoover Dam. There were more than 60 contestants and the prize was won by A. J. Dole, mechanic for the Department of Water and Power, whose guess of the time in transit was 254 hours, the actual time being 255 hours and 25 minutes. The presentation of the electric razor was made by F. A. Latham, Superintendent of Hoover Power Plant for the City of Los Angeles.

The installation of the new bearing at Hoover Dam was supervised by the General Electric Company, the work being done by the Department of Water and Power. Unit N-7 was initially restarted on March 15, the third day after receipt of the bearing parts at the Hoover Plant. After the initial start, which was c tinued until the bearing temperatures became consta it was given a total of six starts. The bearing was th judged to be in good operating condition and turn over to the City of Los Angeles, Department of Wa and Power. The maximum recorded bearing tempe ture of the new up-to-date thrust bearing installed Unit N-7 was 66.5 C compared with 76.5 C for t bearing replaced. Thus was accomplished the success installation of the new bearing with most satisfacto temperature test results (Figs. 2a and 2b).

Early History

Hoover Dam, because its machines have had Ge eral Electric spring thrust bearings dating from t designs of the early 1930's, makes an ideal place install a modern bearing and get direct comparison It was the first of the really large hydroelectric develo ments of the Bureau of Reclamation.

The first units, N-1, N-2, N-3, and N-4 were p chased in 1933 for the Department of Water and Powe City of Los Angeles. The generator specificatio allowed either a General Electric spring-type thru bearing or a Kingsbury adjustable type. The Gener Electric Company was awarded Units N-1 and N- and its bid stated that it would furnish the type thrust bearing preferred by the operating agent of t units—that is, the Department of Water and Powe City of Los Angeles.

At that time the General Electric thrust bearing co sisted of a grooved rotating plate or runner rigid attached to the shaft by means of a thrust collar, relatively thin and flexible babbitted stationary pla and a flexible support consisting of a number of p compressed springs. (Fig. 3.)

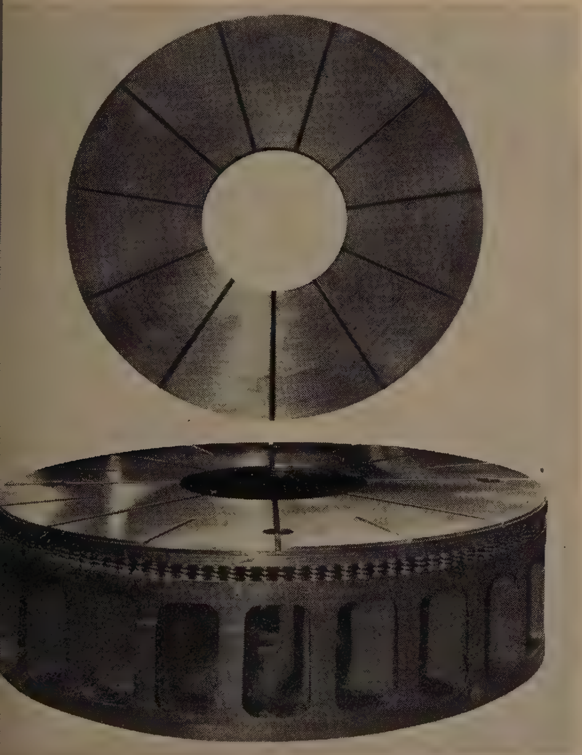
The Kingsbury adjustable type thrust bearing co sisted of a smooth rotating plate or runner and a nu f babbitted shoes or segments each pivoted near enter on an adjusting screw by means of which levation of the segment was changed to approxi- equal loading on the various shoes.

or to the authorization to proceed, all power was acted for and on a basis that would repay the investment over a period of years. Although the ications for the electrical apparatus were drawn ontracts let by the Bureau of Reclamation, the ications and purchase of apparatus were subject e approval of the operating agent responsible for ation and delivery of power to the parties con- ng to purchase the power, and through this power ase to pay for the equipment.

e Bureau specifications were prepared under the ion of L. N. McClellan, then Chief Electrical neer, now Chief Engineer of the Bureau of Recla- n. A preliminary draft of the specifications for the ators was submitted to all manufacturers and to ower users for comments. Later, meetings were at the Bureau Offices in Denver of all those inter- and the specifications revised until the require- s were fully satisfied, and final specifications were l for bids.

n of Flexibly Supported Plate During Operation

r consideration of the engineers of the Department ater and Power and of the Bureau of Reclamation, eneral Electric Company had carried out an ex- ve program of tests and investigations to accumu- data to substantiate the theory of the bearing n.



3. General Electric spring-type thrust bearing installed in Units and N-2 at Hoover Dam in 1936. Bearings, which are 88 inches in eter, are still giving perfect operation

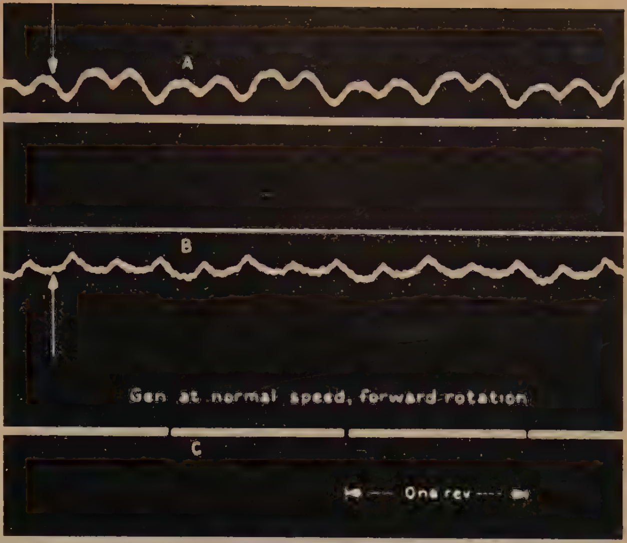


Fig. 4. Oscillogram showing downward deflection of stationary flexible plate at normal speed.

The arrows indicate the direction of deflection (the element for record *B* was reversed.)

A: Opposite radial saw cut
B: At radial saw cut
C: Timing line

(The small high-frequency ripples are unfiltered harmonics of the testing circuit, and are present on the record with the machine standing still.)

The action of the stationary plate under starting and operating conditions had been analyzed and observations were made by means of an oscillograph which substantiated the analytical results.

The observed movement of the stationary plate indicates (Fig. 4) that the oil film is of an alternately diverging and converging shape. This variation in thickness takes the form of waves or ripples, each following a rotating oil groove. (The runner used in the test had four radial grooves.) These waves are continuous over the entire plate, including the radial saw cut, although the magnitude at that point is somewhat different. The oscillogram in Fig. 4 shows the motion of the stationary flexible plate during operation at normal speed. The springs for this test were precompressed to the equivalent of 4.5 times the test load. The nature of this motion is essentially independent of the degree of precompression of the springs.

The oscillogram also illustrates a unique feature of the bearing; namely, its ability to adjust itself to conditions of misalignment which may occur during installation or during subsequent operation. The thrust collar in the bearing for which tests are shown was made 0.0015 inch higher on one side than on the other. This difference introduced an irregularity in the deflection characteristics during rotation, the plate assuming a position inclined slightly to the horizontal, as indicated by the sequential variations in the oscillogram. In spite of this irregularity, the waves are essentially equal in area from one position to the other, showing complete automatic equalization of pressures.

The minimum value of the variable oil-film thickness already described is of the order of a few mils, and depends on such factors as load, speed, and oil viscosity

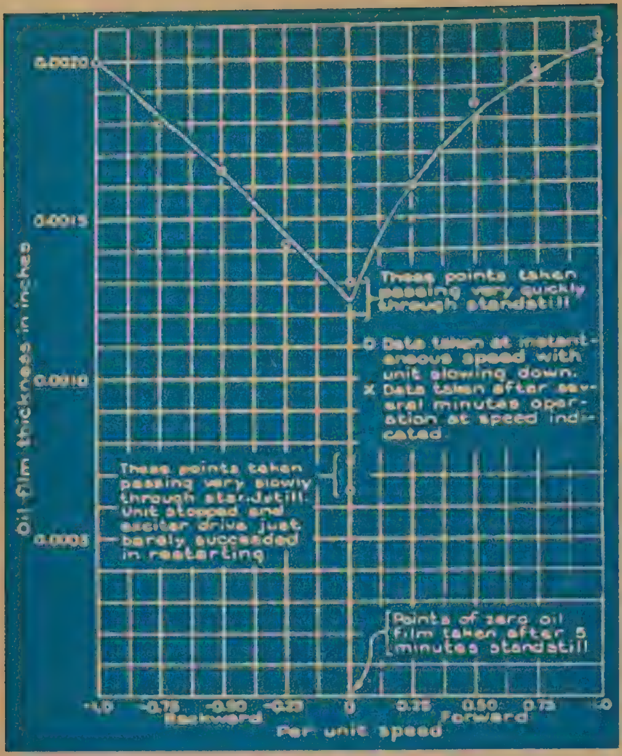


Fig. 5. Curve showing variation of oil-film thickness with change of speed

The curve reproduced in Fig. 5 shows the variation of minimum film thickness with regard to speed for a particular machine. It is not proportional to speed alone, but also involves time in a rather complicated manner. If a machine comes to rest after an oil film has once been established, that film persists for an appreciable time. The film has, therefore, an essentially stable characteristic not readily destructible by pauses of short duration. Because of the residual oil film at zero speed, a very large machine, after it has started to rotate, can be maintained in motion by hand by one or two men. Two men can often restart a large machine and keep it rotating by hand after it has been stopped for an instant.

This stability of the oil film was also well demonstrated in another G-E thrust bearing of 92 in. outside diameter with a normal speed of 88 rpm. As a result of a series of incidents, this bearing operated for several hours at 2 to 3 rpm, successfully carrying the weight of the rotating parts, about 1,400,000 lb. Previously, it had been assumed that operation of any thrust bearing at low speeds was dangerous and that operation of the nature described would cause any bearing to wipe immediately.

The results of these tests and the theoretical performance data were submitted to C. P. Garman, then Assistant Electrical Engineer, now Chief Electrical Engineer and Deputy General Manager for the City of Los Angeles, Department of Water and Power, and other engineers of the City of Los Angeles. On the basis of the data submitted, Messrs. Garman and McClellan decided to specify the General Electric design of thrust bearing for Units N-1 and N-2. The N-2 un went into commercial operation October 22, 1936; an the N-1 unit, December 28, 1936. Except for the wipin of the thrust bearing on Unit N-2 in February 193 because of shaft currents caused by the accident grounding of a test lead, these two bearings have give and are giving perfect operation.

Development of the Smooth Runner

It should be noted that several bearings havin smooth runners were put into successful operation i the period 1914–1916. These were small low-spee bearings; and as larger sizes with higher losses wer developed, grooves were introduced to augment th volume of oil circulated, and this became the standar bearing for a long period of years.

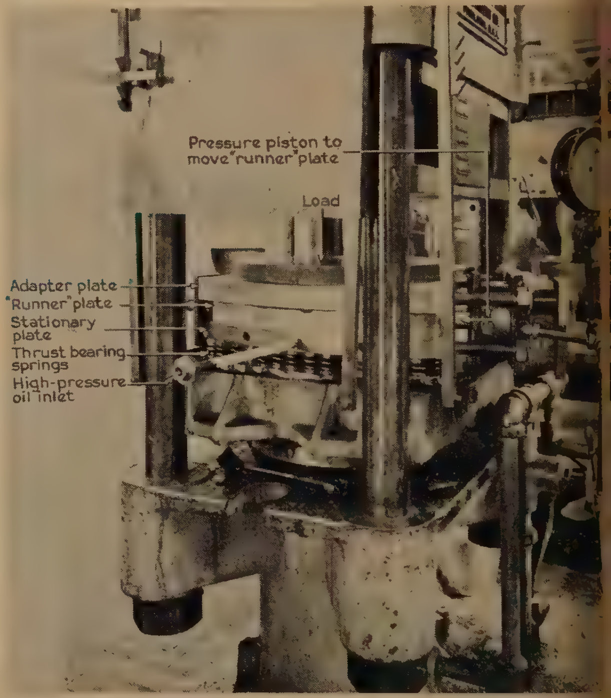


Fig. 6. Test setup to determine the effect of oil pressure starting on segment of large G-E spring thrust bearing

In 1938, in preparation for submitting a propositio on the Grand Coulee 65,000-hp pump motors, it seeme desirable to consider again the feasibility of a smoot runner. It was evident that for certain methods starting it would be very desirable that the breakawa torque on these Grand Coulee pump motors be hel to a minimum. One way to accomplish this was design the thrust bearing for high-pressure oil lubr cation during the starting period. The standard thru runner with radial grooves for increasing the oil circ lation could not be used because when the groov stopped over the high-pressure oil entrance in th stationary plate, sufficient oil pressure could not developed to separate the surfaces. Therefore, the u of a smooth runner seemed to be indicated.

Factory tests were made to determine the effect oil pressure starting on the coefficient of friction and determine the best means of introducing the pressu the optimum shape of the grooves in the babbitt, t m pressure, etc. The test setup is shown in

d on these tests a bearing was designed, and—
e co-operation of the Corps of Engineers—was
d in one of the Bonneville units. It was decided
ace the stationary plate, made up in six pieces
segments each, as shown in Fig. 7, with 12
ual segments, two of which are shown in Fig. 8,
r to provide more room for the entrance of cool
the plates. This developmental installation was
ful in every way and was the basis for quoting
and Coulee pump motors some 8 years later. It
dicated the possibilities of improved operation
he smooth runner and individual segments for
lications, and this type of bearing, without oil
e starting equipment, was installed in other
ville units and in several other plants. Operating
nce on these installations proved the superiority
bearing and in 1945 this became the General
c Company's standard bearing.

h the changes made over these years, the Gen-
lectric spring-type bearing and the Kingsbury
f adjustable bearing become practically identical
parts used, the major difference being that the
ary segments of the General Electric bearing are
ted on a bed of springs which automatically
themselves for load distribution. In the Kings-
ype of adjustable bearings, adjustable shoe type
ts are rigidly supported on pins requiring that
rface be modified to offset the shoe deflection to
equal load distribution across the shoe. The load
ution of the adjustable shoe type between the
ual shoes is obtained by setting each individual
shoe so that the running surfaces come exactly in the same plane. With the General Electric spring-type bearing, what is necessary to obtain the load distribution is the manufacture of flat and parallel surfaces, which can be produced, measured, and duplicated by normal machine processes. This, with the self-aligning feature of the General Electric spring support, results in considerable savings in time during the original installation, and at times of future maintenance operations.

Antimony-arsenic-lead Babbitt

Early in World War II, tin scarcities led the General Electric Company to investigate the use of other materials, in an attempt to find a bearing material which would be superior to the standard tin-base babbitt then in use, and permanently replace it. Through the efforts of the Company's Research Laboratory and alloy manufacturers, a suitable antimony-arsenic-lead babbitt was developed for use in G-E bearings. This was first applied in a 2500-kva 150-rpm unit furnished the Consolidated Water Power & Paper Company in 1942. Inspection after one year's operation showed the bearing to be in perfect condition. In October of 1943, an installation was made on Unit No. 9 at Bonneville which carries a load of 3 million pounds. In July 1946, a bearing of this composition was installed on Unit N-7 at Hoover Dam. Initial and succeeding inspections at Bonneville showed the new babbitt to be in perfect condition, and the Hoover plate was found to be in the same state after 3 years of operation. Meantime, upon conclusion that, for all installations where the acidity of the oil can be and is controlled, the new babbitt material was in all respects equal to the older tin-base babbitt, and was superior in its resistance to fatigue, and in that it has practically eliminated the scoring of rotating plates, the new babbitt was standardized for thrust bearings. However, continual alertness is

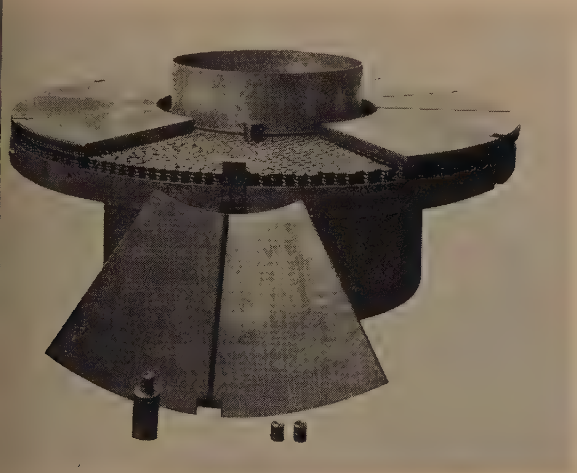


Fig. 7. Stationary parts of original thrust bearing installed in generators at Bonneville Dam. Stationary plate consisted of 6 pieces of 2 segments each

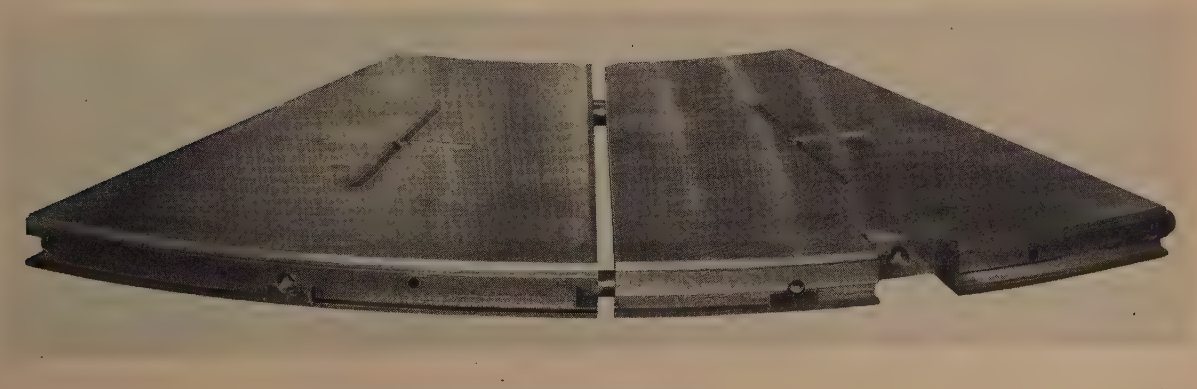


Fig. 8. Two of 12 individual segments making up stationary plate of developmental bearing used at Bonneville. Grooves on each segment are provision for high-pressure oil starting

maintained to recognize new developments that may lead to still better babbitt materials.

Refinement of Spring Manufacture

Two minor refinements have been made in another component of the bearing—the springs. The screw and threaded washer which provide the precompression of the spring are now locked more securely against loosening. Present practice is to braze these parts together. In addition, methods of machining the spring assemblies have been improved to work to closer tolerances than previously. This is especially important in smaller bearings where the number of springs under a segment is small. It is, however, of value throughout the line.

Conclusion

Summarizing, the General Electric spring thru bearing as now standardized with smooth runner, se mental stationary plates, and with the new antimon arsenical-lead babbitt, gives a bearing which can started as frequently as desired with no special pr cautions; can have oil-pressure starting added whe low breakaway torque is of real importance; is n subject to the variations in pressure which accompan the operation of the grooved bearing; with segment individually free to deflect to permit the optimu angle for the formation of the oil wedge; and wit somewhat lower temperatures than prevailed in th earlier bearings.

HIGH LIGHTS AND SIDE LIGHTS

Gigantic Camera

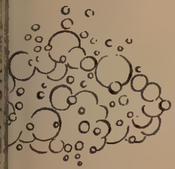
Modern fluorescent and incandescent streetlights are tested inside this 75-ft chamber, which acts as a camera and focuses light upon the test stand at the far end, where an engineer is adjusting a light-intensity meter. The circular curtains, or flanges, keep the light from being reflected in the darkened chamber

Television in Reverse

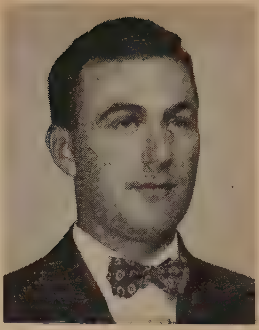
Reversal of the coil controlling reception of the televised image adapts a television set to use by an iron-lung patient. He now sees the normal picture in his mirror

AMS

anted foaming, which occurs in industry and in the prepa- n and the use of certain products, may cause damage ne product, impairment of efficiency, and financial loss



By DR. SYDNEY ROSS
Associate Professor of Colloid Science
Rensselaer Polytechnic Institute
Troy, New York



Sydney Ross

ERY HOUSEWIFE who has had the disturbing xperience of seeing a pot of soup or vegetables ver has some idea of how troublesome a stable can be. Every convivial soul who has plunged a ener joyfully into a can of beer only to have it his face and necktie similarly realizes some un- nt aspects of unwanted foam. In the field of rial manufacture, however, this problem is in- d many times by the larger scale of operation y the greater risk of financial loss. It is no wonder large number of industrial engineers and manu- ers take a lively interest in the question of how vent unwanted foaming.

etimes the foaming takes place in tanks or con- s at boiling temperatures, and much more space be allowed to contain the additional volume of ial. Sometimes the foaming takes place when the ial—tomato juice, for example—is being put into and causes the can to fill up with foam; nobody arket a can of tomato juice that is less than half And sometimes the foaming does not take place the product is sold and the customer tries to use herever unwanted foaming occurs, it is a real and imes desperately important problem to the manu- rer. To give an idea of how widespread this prob- , here are a few examples.

trial Problems

greatest problem, in terms of frequency, per- cy, and damage to the product, is in the manu- e of paper. The pulp is often found to foam y at the paper-making machine, sometimes over- g onto the floor, and even when less obviously a ce than that, always resulting in paper of unequal e and poor appearance. No industry has tried ore remedies more hopefully and less success- than has the paper industry. A large quantity of has to be processed for a small quantity of paper, lthough the chemical antifoaming agent is present in a small concentration, it soon adds up to a amount, thus unduly increasing the cost of facture.

problem equally large is presented by steam es. For many a year railroad companies have been testing methods of treating the water used in the steam boiler, to prevent its foaming and so greatly impairing the efficiency of the engine. A number of different antifoaming agents have been tried out, some with outstanding success. In this field scientific theory still plods a long way behind actual practice. Chemicals are found to work and are used on a large scale while the theoretical physicists and chemists are still arguing. For example, in boiler-water treatment it is still not known whether the polyamide agents that are so very useful are modifying the properties of the water itself or are somehow changing the metallic surfaces of the boiler to produce in contact with them large, unstable bubbles of steam instead of fine, stable bubbles.

Interrelated Problems in Food Production

In food industries a problem of foaming necessarily poses a second problem at the same time. No chemical agent can be incorporated in a food product, even in vanishingly small quantities, unless it first satisfies the rigorous tests of the Pure Food and Drug Act. Many manufacturers of antifoaming agents prefer to leave this potential market severely alone, rather than venture into the jungle of legal interdictions with which it is hedged. A triple problem was presented by a troublesome foam that arose during the production of penicillin. Here the remedial agent was required, first, not to harm the mold; second, not to harm the patient but merely to stop the foaming. A chemical was found to do the trick. Another problem of the food industry is in deep frying where, after a certain amount of use, the fat begins to produce a stable froth that gradually builds up until it becomes a nuisance. A small quantity of calcium stearate destroys this froth.

A traditional remedy used in eastern Canada and New England for reduction of foaming during the evaporation step in maple-sugar production is to hang a small amount of salt pork on a twig directly above the liquid; the rising foam coming in contact with the pork is made to collapse. In Scotland another traditional remedy is used during the distillation process in the manufacture of Scotch whisky. Inside the copper stills the fermented wort could froth over into the receiver and spoil the whisky. To prevent that the distillers put a bar of household soap in the still; soap foams, of course, by itself, but when it competes with

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nted by Dr. Ross as a talk at the General Electric *Science Forum* st on November 1, 1950, from Station WGY, Schenectady, N. Y.—

another foaming agent very often neither of them is able to produce foam. One Scotch distiller had an unfortunate experience: he used a fine brand of toilet soap instead of the usual coarse household soap, and the result of his pains was to transfer the perfume from the soap to his whisky, where it was less appreciated.

The manufacturers of glue are presented with a problem when their products are used in automatic machines, such as those that coat the backs of labels and posters. The material produces a heavy and stable froth that defies efforts to make it lie flat. Even the best antifoaming agents have a hard time with this type of foaming, requiring amounts of agent that are 100 to 1000 times greater than for other applications. But here again modern chemistry ultimately provides the answer, and this problem has been solved. Unfortunately, in some cases the manufacturer finds the remedy almost as great a problem as the disease, as the costs of his product begin to rise.

Oil and Gas Drilling

An interesting case where it is essential to reduce the stability of the froth produced by entrained air is in the drilling of deep wells to produce gas or oil. It is a necessary practice in this operation to circulate a fluid suspension through the well and around the drill. The fluid serves several purposes at the same time. First of all, the circulating fluid lubricates and cools the drill. Next it is intended that the fluid will seal off any cracks or crevices leading to other formations into which the gas or oil might leak in its upward passage through the well. To accomplish this purpose the fluid used is a clay, or bentonite, suspension, which will flow only under direct pressure. When this pressure is not present, the clay sets to a semirigid mass; it is for this reason that the circulating fluid is called "drilling mud."

Finally, the pressure exerted by the hydrostatic head of the drilling mud prevents any sudden escape of gas from the well when the drill finally enters a gas formation containing gas under pressure. Instead of erupting suddenly to the surface, the gas is contained by the pressure of the drilling mud. By a well-known law of physical chemistry a certain quantity of gas is dissolved in the drilling mud under pressure. As the mud ascends the well on the return of its cycle, the pressure is reduced and the dissolved gas begins to come out of solution again, forming bubbles throughout the fluid. This mixing of the drilling mud with gas is called "gas-cutting" and is undesirable, since it results in a lower effective density of the mud and, hence, less containing pressure exerted on the gas formation at the foot of the well.

When gas-cutting occurs even to a slight extent, it is essential that the gas bubbles be released as quickly and completely as possible as the mud fluid reaches the surface and before the fluid is returned to the bore, in order that the mud may not become further gas-cut during the next cycle through the bore. Unless gas is removed when the mud is at the surface, the gas-cutting is aggravated in each recycling of the mud and may proceed to such a degree that the pressure exerted the gas in the gas-bearing stratum exceeds the pressu of the hydrostatic head of the column of gas-cut m above the stratum. The result may be and often is, "blowout." This is a violent ejection of mud and g because of the high pressure of gas in the well.

A "blow-out" is dangerous. It may cause serio fires if the gas becomes ignited, and even if that do not happen, the derrick and pumping equipment m be damaged or destroyed by the escaping gas or rocks and sand blown from the well. Suitable chemi agents have been found, however, to counteract these unwanted effects by destabilizing the bubbl when they come to the surface.

High-altitude Flying

In contrast to the type of foaming which takes pla in the depths of the earth is an equally bothersome o that finds its place in the heights of the air. Many ai craft with internal-combustion engines use the pressu system of lubrication, in which the oil returning fro the engine parts is picked up by a scavenging pum and returned to the lubricant reservoir. As the scaven ing pump normally has a capacity several times larg than the volume of oil returning from the engine, large amount of air is pumped along with the lubrica and foam is built up in the oil reservoir. This foam ma cause loss of oil through the breather pipe, and alwa causes reduced lubrication and heat transfer when o foam instead of liquid oil is delivered to the machiner

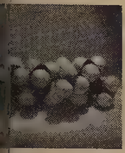
The whole condition is made worse in planes tha take off suddenly and rise to high altitudes, as inte ceptor defense fighters must do. Since the oil is cold an viscous at take-off, the pilots pump gasoline into th oil to reduce its viscosity for a quicker take-off. But the reduced pressures of high altitudes, the gasoli vaporizes and bubbles of gas are formed in the oi Dissolved air also comes out of solution as the pressu is reduced. This condition became a serious proble during World War II, and was only satisfactorily solve by a combination of better engine design and additio of a chemical agent to the lubricating oil that cause the bubbles to break rapidly and so prevented th foam from building up.

Combating Foam by Chemicals

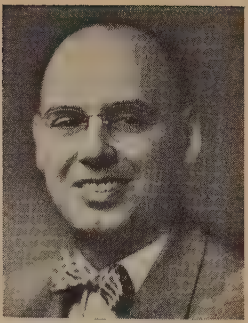
Here have been described a number of situatio where foaming is a problem. The types of chemical tha are effective in combating the problem vary greatly chemical composition, but they have one thing common: they are all surface-active. When a surfac active material is added to a foam it spreads spo taneously on the surface. It may destroy foams mechanical rupture of the film, caused by the stre produced when it spreads, or it may act by supplanti the original foaming agent at the liquid surface. effective agent is one of the organosilicon compoun of the sort described in the article, "Uses of Comme cial Silicone Products," by Dr. R. O. Sauer, in this iss of the GENERAL ELECTRIC REVIEW.

S OF COMMERCIAL SILICONE PRODUCTS

Method of preparation and a brief analysis of the basic molecular structures. The versatility and extraordinary characteristics of today's silicone products contribute to their varied uses and broad application.



By DR. R. O. SAUER
Chemical Department
General Electric Company



Robert O. Sauer

DAY in the United States there are several rge companies, among them General Electric's cal Department, actively manufacturing sili- These concerns probably made several thousand organosilicon intermediates in 1950, and because rapid utilization of these interesting materials, production will probably be expanded consider- 1951. Abroad, several chemical companies are acturing—or at least pilot-planting—similar ts, and it seems certain that additional produc- cilities will soon be available in Europe.

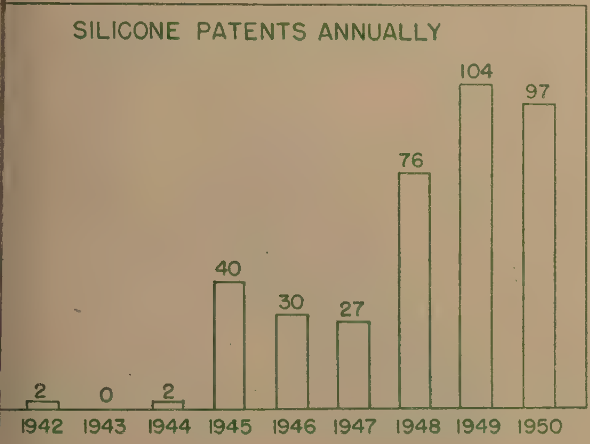


Fig. 1. Total number of silicone patents per year

THE SILICONE INDUSTRY

id It Start?

s industrial activity began in the last decade, rily with the search for more heat-stable var- and stickers for electrical insulation. Much mental chemistry preceded it, some of which back to the late 1800's; for example, diethyl e was prepared and reported by Ladenburg in Sir Frederick Stanley Kipping devoted much of reer to the study of organosilicon chemistry, the period of 1900-1935 he contributed some cientific papers on this subject. Several universi- d colleges in this country, for example, Pennsyl- State College, Iowa State College, and Purdue rsity, have contributed and are contributing to owing fund of basic chemical knowledge in this

A glance at the patent literature indicates the recent and rapid growth of industrial interest in this country. Less than ten United States patents in the silicone field were issued prior to 1940, but by the end of 1950 the total number was close to four hundred. FIG. 1 illustrates in a graphical way this industrial interest. A large number of the patents concern the methyl silicones. These entirely new compositions of matter were unknown in the scientific literature prior to 1940. Silicones, we must conclude, are beginning to take their place in the field of industrial chemicals.

What Is A Silicone?

Broadly speaking, silicones are a class of polymers containing a plurality of silicon-oxygen-silicon linkages in contiguous array, and in which at least a majority of the silicon atoms bear organic substituents through carbon-silicon bonds. Simple molecular structures such as that shown in FIG. 2 would come within this definition. The empirical formula of a silicone is generally represented as $R_NSiO_{\frac{4-N}{2}}$ in which R is an organic radical. This organic radical may contain hydrogen, oxygen, sulphur, nitrogen, halogen, or even silicon, in addition to carbon, but in today's commercial products R is generally a simple alkyl or aryl grouping, for example, methyl or phenyl. These groupings are being made because straightforward synthetic methods exist for them and because a sufficient variation in properties can be obtained by their combination.

This definition of silicones includes a wide variety of R groups. Most of these possibilities have not yet been made commercially, although many are now being studied for their effect on properties and handling techniques. As the result, new silicones will probably be added to the industrial catalog of the future. Even today, because of the possible variations of *N* in the formula given and in the ratio of methyl-to-phenyl

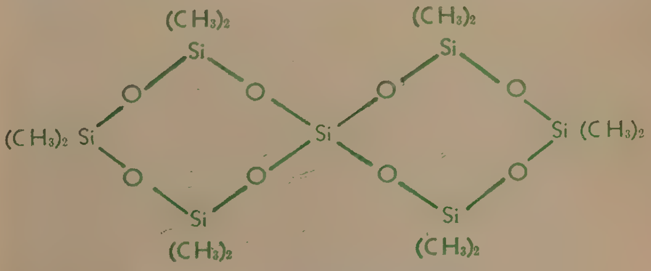


Fig. 2. A low-molecular-weight silicone

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ted as a lecture before the Chicago Section of the American Chemical Chicago (Ill.), February 23, 1951.—EDITOR.

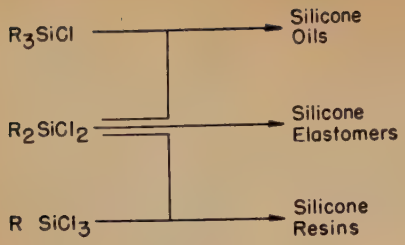


Fig. 3. The relationship of silicone oils, elastomers, and resins to the three functional types of intermediates

groups within a single given value of *N*, a considerable variation in ultimate properties results. Add to these variations in processing and compounding (if a compounded product is involved) and it can be readily seen that *all silicones are not the same.* They differ as much or more within their class as do organic polymers (such as fluorocarbons, alkyd resins, or butadiene-styrene copolymers). The general statements which follow regarding properties apply to those products based primarily on methyl or methyl-phenyl compositions. Even within this limited composition region there exist wide differences in properties such as high-temperature life, low-temperature flexibility, curing rates, and toughness.

How Are Silicones Made?

In terms of present-day manufacturing methods, the silicones are derived by hydrolysis from intermediary silanes of the type R_NSiX_{4-N} where R has the significance previously described and X is a hydrolyzable grouping, for example, halogen or alkoxyl. (In this formula *N* is an integer from 1 to 3.) Alkyl or aryl chlorosilanes can be made by the direct reaction of silicon with an alkyl or aryl chloride. In general, silanes with three chlorine atoms, with two chlorine atoms, and with one chlorine atom are produced. Equation (1) shows the products from the reaction of methyl chloride with elementary silicon.

$$6CH_3Cl + 3Si \longrightarrow CH_3SiCl_3 + (CH_3)_2SiCl_2 + (CH_3)_3SiCl \quad (1)$$

Fig. 4. Silicone oil flows freely at –100 F

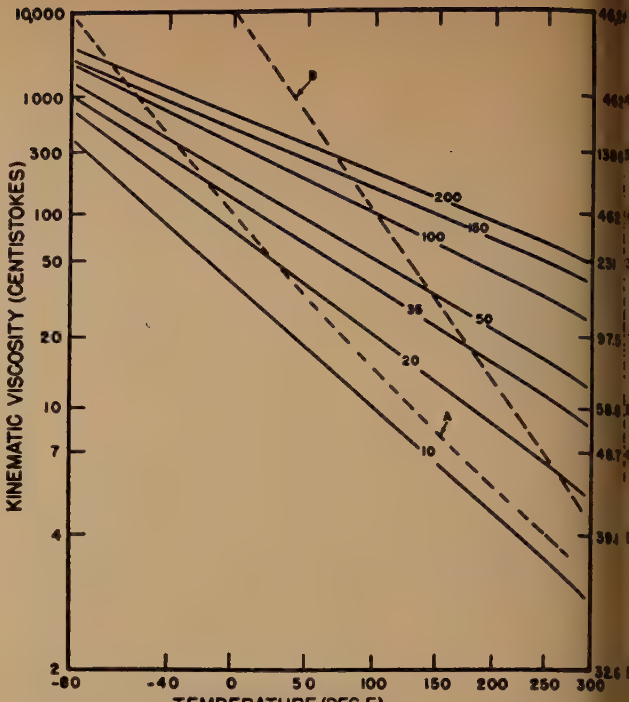


Fig. 5. Curves showing viscosity vs. temperature of silicone oils (solid lines) and petroleum oils (dashed lines)

Fig. 6. An aircraft gun-charging motor lubricated with silicone oil

A second general synthetic method is the replacement of a portion of the chlorine of silicon tetrachlorid or the ethoxyl of ethyl silicate by a hydrocarbon grou ing. This may be effected by means of the Grignard o organosodium reagents, as in Equation (2).

$$2\,RMgCl + SiCl_4 \longrightarrow R_2SiCl_2 + 2\,MgCl_2$$
$$2\,R{-}Na + Si(OC_2H_5)_4 \longrightarrow R_2Si(OC_2H_5)_2 + 2\,NaOC_2H_5 \quad ($$

A third process, which is particularly valuable f simple alkyl groupings higher than methyl, involves th addition of silanes containing silicon-hydrogen bon to ethylenic linkages either at relatively low pressur in the presence of peroxy catalysts or under pressu at higher temperature but without catalysts, as Equation (3).

$$R{-}CH{=}CH_2 + HSiCl_3 \longrightarrow R{-}CH_2CH_2SiCl_3 \quad ($$

a good synthetic method for the trichlorosilanes e trichlorosilane $HSiCl_3$ can be easily prepared ydrogen chloride and silicon.

erally speaking, it seems desirable to have avail- termediates of the three functional types—that is, , R_2SiCl_2, and $RSiCl_3$. On hydrolysis these ediates yield siloxane units which are the build- ocks of the polymers known as silicone resins, fluids, and elastomers. The relationship of these ts to the intermediates mentioned is shown in

CONE PRODUCTS—THEIR CHARACTERISTICS

oes One Actually Buy?

se major products are usually sold in the follow- ysical forms:

ns: As solutions up to 80 percent solids in hydro- rbon or ketonic solvents.

tomers: As gums—that is, 100 percent silicone, (and this is the principal form) as gums com- unded with fillers and curing agents.

: As fluids (100 percent silicone) in a variety of scosities, or as emulsions with water containing nerally about 35 percent silicone fluids.

eneral properties of silicones which make them in today's applications are:

Their resistance to heat and cold

Their nonsticking or release qualities

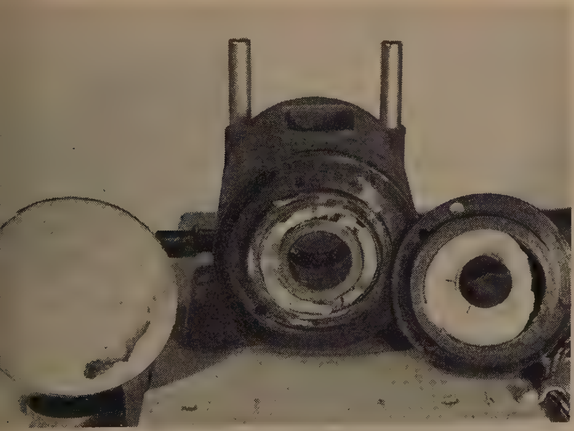
Their production or possession of useful surface teristics

Their inertness.

now look at these general properties individually specific products which illustrate them and their rial application.

nce to High and Low Temperature

t silicones resist high temperatures may be at- ed to the thermal and oxidative stability of the -carbon bond. Their behavior at low tempera- is probably associated with the flexibility of the -oxygen-silicon bond angle.



. Test bearing packed with silicone lubricating grease as it appears 000 hr operation at 300 F. Tests are still in progress which indi- at this grease is useful after more than 9000 hr in a 306 ball bear- erating at 3600 rpm

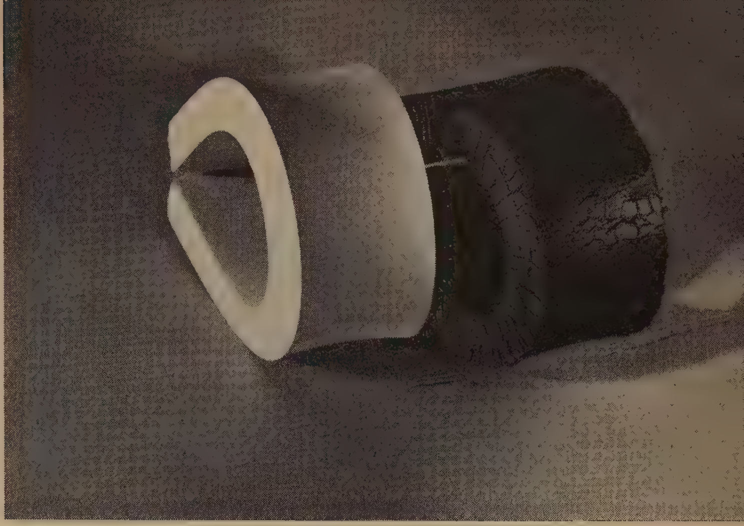


Fig. 8. After exposure for 36 hr at 300 F, the surface of conventional rubber decomposes, while the surface of silicone rubber is unaffected after 100 hr at 400 F

The methyl silicone oils exhibit small changes in viscosity with temperature and unusually low pour points. The latter property is demonstrated in Fig. 4. Here a petroleum oil and a silicone oil of like viscosity at room temperature have been chilled to −100 F. The petroleum oil has congealed while the silicone flows freely. Fig. 5 shows viscosity plotted against temperature for some silicone fluids and two low-temperature hydrocarbon-base oils. This property of low change in viscosity with temperature of silicone fluids is being used to advantage in a fluid vibration damper. This damper is attached to the free end of the crankshaft of four- and six-cylinder, or even 8-cylinder (in line) engines. By virtue of an inertial mass which floats on a thin film of viscous silicone oil, the torsional vibration of the crankshaft is reduced at all speeds. A further advantage of the silicone fluid in this application is the small change in viscosity with varying rates of shear and its resistance to shear breakdown under the high shearing forces (the oil film is but 20 mils thick). Because considerable energy is absorbed by this damper at resonance speeds, the oil must have great resistance to thermal breakdown.

A second application (Fig. 6) which illustrates the viscosity-temperature characteristics of the silicone oils is their use in the lubrication of aircraft gun-charging motors. This oil permits sure and rapid starting even at temperatures below −100 F. These oils can be used to formulate high-temperature lubricating greases such as that shown in Fig. 7.

Silicone rubber also combines good high- and low-temperature properties (Fig. 8). Conventional rubber chars and cracks after exposure at 300 F for only 36 hr, but silicone rubber made from a dimethyl silicone-base polymer remains flexible and resilient after 100 hr, and sometimes from 3 to 6 months at 400 F. Silicone elastomers generally show good resilience and flexibility at remarkably low temperatures; some special stocks remain elastic and pliable at below −100 F. While the physical strength, abrasion resistance, and elasticity of silicone rubber at ordinary temperatures are not as great as those of natural

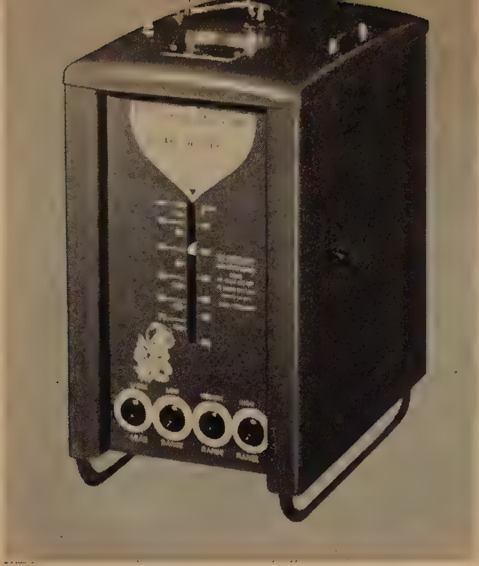


Fig. 9. This welder wound with silicone insulation is compact, light weight, and has a high margin of safety

or some synthetic rubber stocks, the mechanical properties are far superior after exposure at elevated temperatures. Table I gives the properties of a silicone rubber and shows the degree to which these properties are maintained after heating at 480 F for 24 hr. Other grades now available include special low-compression-set and low-temperature stocks.

Silicone rubbers are used primarily as high- and low-temperature gasketing materials and as high-temperature electrical insulation. The turbosupercharger and cylinders of some diesel engines are separated by silicone rubber gaskets which operate at 300 F.

Silicone resins and elastomers are used for electrical insulation because they maintain excellent electrical properties at high temperatures, exhibit phenomenal low-temperature flexibility, resist the penetration of moisture, and on burning or arcing leave a residue of silica which is electrically nonconducting. Also, combustion yields no acidic or corrosive products. These properties are of interest to manufacturers of control or power cable for aircraft and naval uses and to c signers of ignition cable for military vehicles.

TABLE I: PROPERTIES OF SE-450 SILICONE RUBBER

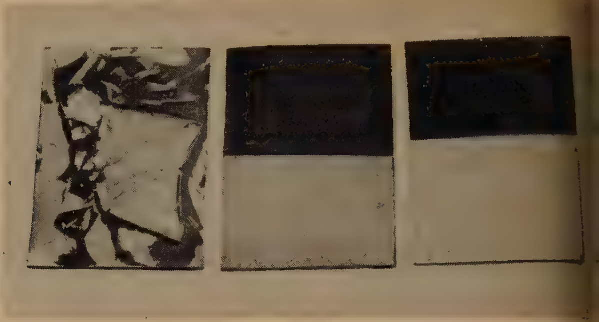
	Curing Time	
	1 hr/300 F	24 hr/480 F
Durometer, A Scale	40±5	50±5
Tensile Strength, psi, min.	800	600
Elongation, percent, min.	400	240
Tear Strength, Die C, lb/in., min.	80	65
Specific Gravity	1.1–1.2	1.1–1.2

ELECTRICAL DATA

Specimen Thickness: 0.085 in.
Curing time: 16 hr at 480 F (optimum for best electrical properties)

	50 percent RH	4 days at 95% RH
60 Cycles 500 volts, 25 C		
Dielectric Strength, v.p.m.	370	432
Dielectric Constant	3.56	3.48
Power Factor	0.0081	0.010
Insulation Resistance—ohm-centimeters	6.63×10^{14}	2.46×10^{14}
1 Megacycle		
Dielectric Constant	3.1	
Power Factor	0.0016	
10 Megacycles		
Dielectric Constant	2.9	
Power Factor	0.0019	

Fig. 10. Specially formulated silicone protective coatings are unaffect by high temperatures while a conventional type (*at left*) peels and crac



The use of silicone resins in electrical machine permits continuous operation at hot-spot temperatur of about 50 C (by AIEE standards) above the limit f Class B insulation (130 C). Motors, generators, or tran formers are often designed to operate in this high temperature range because of high ambient temperatur or the inability to cool the device conveniently, or b cause a greater output is desired per unit of weight volume than that allowable with conventional insul tion. A recent example of such utilization of t properties of silicone resin insulation is shown in FIG. If the welder transformer shown were wound wi Class B insulation, it would be necessary to constru the frame much heavier. In fact, this welder weig about one-half what it would if Class B insulati were used; a greater margin of safety was built into t product; and the transformer is more water-repellen

The general resistance of silicones to decompositi at high temperatures is proving of value also in t formulation of industrial finishes. The use of silico resins as vehicles in aluminum-base paints has ma possible protective coatings which do not flake deteriorate at 750 F. When higher temperatures a encountered, the silicone resin decomposes but at rate slow enough to permit bonding of the aluminu pigment to the steel beneath it. FIG. 10 shows:

(1). An alkyd-aluminum finish which has deteri rated after only two hours at 1000 F
(2). A silicone-aluminum finish after 72 hr at 1200
(3). A silicone-aluminum finish after 24 hr at 1000

There are also many applications now using vitreo enamels which can be adapted to silicones, but present these are mostly in the developmental stage.

Release from Sticking

From the theoretical viewpoint, little can be sa concerning the nonsticking or release property, though it is probably related to the unusual molecu structure of the silicones and the consequent uniq solubility and surface characteristics.

Silicone oils have been found to release rubber a plastics from molds. The use of silicone mold-rele particularly for tires with intricate tread de- as proved an advantage in the rubber industry. es' ability to release is being utilized also in molding and in preventing the sticking of washers to metal flanges in steam-line couplings, mple, on Pullman cars. Silicone resin coatings en used on bread pans to eliminate greasing and bsequent carbonization and smoking of the This silicone coating has been improved so that lasts for as many as 500 bakes.

one coatings can prevent the adherence of other als, for example ice (used in de-icer boots), rub- eated paper sheets used between layers of tacky stock), starch-to-metal (during ironing of d clothes), and it can even prevent Scotch tape icking to paper (Fig. 11).

e Properties

ird general property of silicones is their unusual properties. One of these is the ability to *sup- oam*.

ajor application of this effect is in the lubricating d. Many of the recent improvements in lubri- oils, such as resistance to sludging and better ty, are accomplished by the use of additives. same additives sometimes create special problems r own, one of the most critical being foaming. ple adding of an appropriate silicone oil in small ts this problem has been largely eliminated. Also eous media, foaming such as that caused by or detergents can be controlled.

water repellency of silicones has already been oned. This is another unusual surface character- hich is being utilized. In one large-scale applica- lass mat is made water repellent and used in life s. Fig. 12 illustrates the effect. Also, silicone are being incorporated into masonry-finishing als to improve the water repellency and inci ly the weathering characteristics of the masonry. is some promise that silicones will find a place in eatment of textiles to contribute water repel- better drape, and crinkle- and crease-resistance.

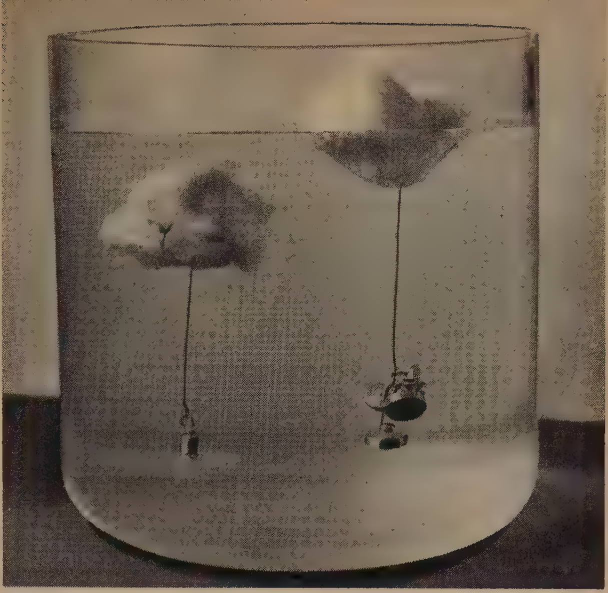


Fig. 12. Glass matting treated with a silicone remains buoyant even when additional weights are attached

ough the reluctance with which silicones stick er substances has been emphasized, this reluc- can be overcome. Special compounds are available to cause the firm adherence of metals, ceramics, and other materials to themselves or to one another where bonds must be created to withstand high temperatures. *Silicone adhesives* are capable of gluing any type of silicone rubber with a tough, flexible, heat-resistant bond. One example, a rather modest one, is the fabrication of large "O" rings for gaskets. Here the rubber compound is extruded and cut to the proper length. The ends are then treated with adhesive, spliced, and cured to give a bond as heat-resistant and as strong as the rubber itself. The use of silicone sealing compounds and their adherence to metals is illustrated in the manufacture of the General Electric steam iron (Fig. 13).

Silicone oils have a rather low surface tension. This is one reason they work so well as mold-release agents for they spread rapidly. This ability to *wet* surfaces readily has already found many practical applications, such as in waxes or polishes for automobiles. New easy-to-apply furniture polishes are also possible with silicone oils. Several of these have just come, or will come, on the market. Such polishes cover furniture with an invisible protective film and leave a lustrous finish. Silicone oils have been added also to new-type cleaners and polishes for leather, metal, and plastics.

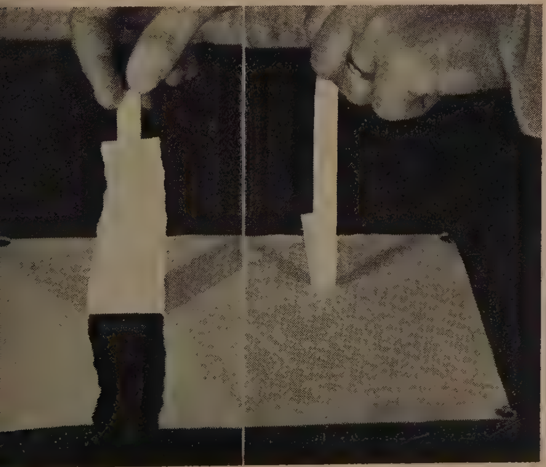


Fig. 11. Silicones prevent unwanted sticking of cellophane adhesive tape

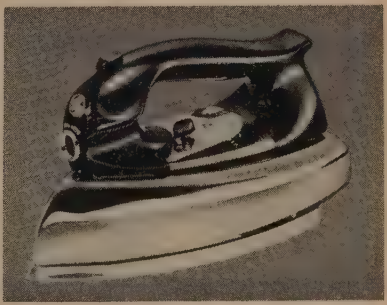


Fig. 13. In this newly designed flatiron a silicone adhesive is used to seal the filler tube to the cap, and the cover to the sole plate and to the iron tank

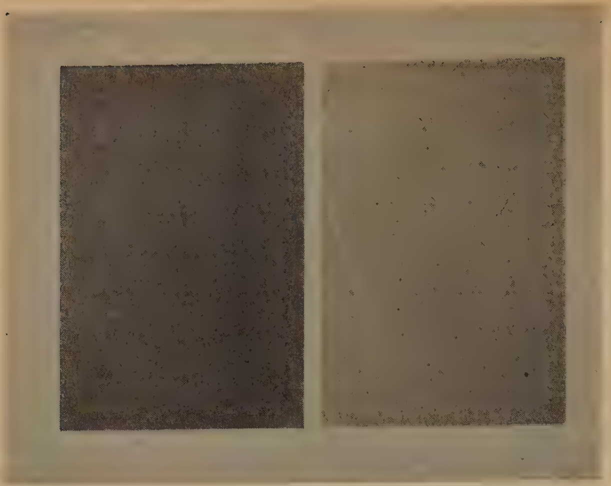


Fig. 14. Exposed for three years to Florida sunlight, the silicone enamel (*right*) showed very little change in color or gloss as compared with alkyd sample (*left*). During this period the silicone showed no tendency to "chalk"

The *arc resistance* of silicones is usually high because no conducting carbon particles are formed by the arc. It may take as few as three seconds for an arc to track across a phenolic molded part. Melamine compounds are considerably better. But now silicone molding compounds offer extremely good arc-resistance properties, sometimes up to 250 sec or better. A dielectric grease made from silicone oil is used in ignition harnesses for aircraft. In addition to its heat and moisture resistance it, too, has good arc resistance and low loss factor.

Inertness

A general property of silicones is their inertness toward oxidation. Then, too, they have some modest resistance to chemical or solvent attack; and they do not rapidly deteriorate on exposure to sunlight, to moisture, to weathering, or to ozone.

This inertness promises to make protective coatings far superior to anything now available, for they already set new standards for heat resistance and color and gloss retention. These paints resist dilute acids and alkalis and the staining effects of drugs and fruit juices. For outside use, they promise great resistance to the weat ering action of moisture, sunlight, and ozone (Fig. 14 Silicone rubber, for example, is also resistant to ozo and to solvents, such as alcohols and certain chlorinat hydrocarbons. The latter property, together with i resilience and arc resistance, qualifies it for use in t G-E capacitor (Fig. 15) where it is used as a gaske ing material around the two leads.

Because silicone rubber is not vulcanized by t usual rubber chemicals, it contains nothing after curi which would attack common metals. A similar stat ment applies to the silicone oils.

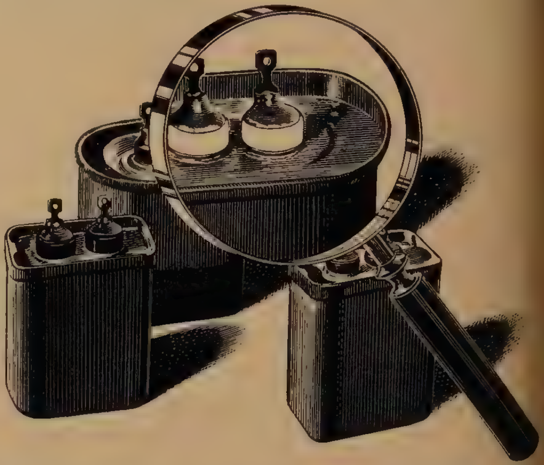


Fig. 15. Silicone rubber bushings improve performance of Pyranol*-filled capacitors

* Reg. trade mark of G.E. Co.

Summary

The purpose of this article has been to show som thing of the silicone industry, the raw material the method of preparation, and the molecular stru tures on which these materials are based. This present tion has been restricted to uses of silicones which a already established, and these uses have been describe under the four general properties that the presen day silicones appear to exhibit: resistance to heat an cold; unusual release qualities; useful surface chara teristics; and general inertness.

HIGH LIGHTS AND SIDE LIGHTS

Plastics for Bobbins

Jute bobbins molded from rubber-phenolic compound are replacing wood in bobbin applications because of their greater strength, lightness in weight, and lower cost.

For use in one weaving mill, a flock-filled rubber-phenolic compound has been specified for bobbins designed to hold carpet jute.

With wood bobbins formerly used, chipping and splitting resulted from rough handling in mills. Having outstanding resistance to impact, rubber-phenolic bobbins stand up under this severe abuse and, being 20 percent lighter in weight, save on shipping costs. Faster calculation of shipping weights is also made possible by the greater uniformity of size and weight.

The increased use of rubber-phenolics by the textile industry is prompted by the outstanding shock resistance of these materials, which is obtained by nitrile rubber.

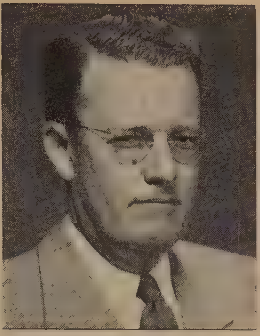
It is anticipated that other important ne markets will be opened up for plastics a plications as a result of rubber-pheno development.

Rubber-phenolic bobbin

SE EVALUATION OF FLUORESCENT LAMP BALLASTS

mary of previous approaches. A system has
d which may provide the basis for industry
cations and standards covering ballast-
measurement. Further study encouraged

By C. P. HAYES* and H. R. GOULD
Specialty Transformer and Ballast Divisions,
Apparatus Department, General Electric Company



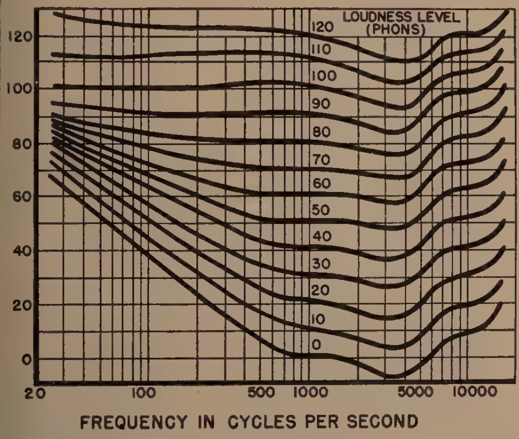
C P Hayes

Herbert R. Gould

This paper was awarded First Prize in the General Applications Division, AIEE, announced in the February 1951 issue of ELECTRICAL ENGINEERING.—EDITOR.

E fluorescent lamp is a gaseous-discharge device
d, therefore, if connected to a constant-voltage
it will draw more and more current until the
s destroyed. A ballast, or impedance, must be
ted in series with the lamp to limit the current
value for which the lamp was designed. Because
amps usually require various voltages to start
the ballast also includes a means for transform-
available circuit voltage to the proper voltage
rting the particular lamp. For 60-cycle alternat-
rent systems, the most efficient means of limiting
rrent is by a reactor, and the usual device for
transformation is the transformer or auto-
rmer. Although many combinations now are in
r various lamps and for multilamp operation,
all such devices are made up of laminated core
ures of magnetic steel and copper windings.

se assemblies, like other electromagnetic devices,
ource of audible radiation. Noise may be defined
esired audible radiations as contrasted to pleasing
, such as music. Under certain conditions, how-
ny of these audible radiations may be undesired
ence, become noise. Although many devices make
f relatively high levels—such as the automobile, the vacuum cleaner, and the adding machine, to name a few—light sources through the ages have been relatively quiet. The early campfire was accompanied by a characteristic crackle, but more recent light sources—such as the oil lamp, the candle, and the incandescent electric lamps—are almost devoid of noise.



Loudness level contours for response of the human ear with
ons in the frequency of sound

The past two decades have seen tremendous strides toward quieting of nearly all types of equipment, such as the automobile, the clock, and the electric refrigerator. However, the introduction of the fluorescent lamp brought an appreciable *increase* in noise to lighting of this type, while the whole environment of modern man was enjoying a great reduction of distracting noise from other devices. This made the job of the ballast designer a difficult one because, compared to other electromagnetic devices, the ballast was relatively quiet; but in low-noise-level locations, the ballast was an irritating source of noise.

The human ear varies greatly from individual to individual and from time to time, but many exhaustive tests by hundreds of observers have established that the ear can detect frequencies as low as 20 or 30 cycles, increasing in sensitivity to a maximum in the vicinity of 4000 cycles. Sensitivity tapers off again, and the ear can detect no noise at some point between 10,000 cycles and 16,000 cycles (FIG. 1).

The fluorescent lamp, because of its nonlinear impedance characteristics, draws current of high harmonic content through the ballast. As a result, the ballast has a frequency spectrum similar to the ear-response curve. Typical frequency spectra of ballast noise are shown in FIG. 2. The elimination of these harmonics of the 120-cycle fundamental would help to reduce noise and reduce its objectionable qualities, but little progress has been made along this line of attack.

Noise generated by the ballast usually is greatly amplified by the lighting fixture in which it is used. The relationship between the ballast, as the generator of noise, and the fixture, as the amplifier of noise, is shown in FIG. 3.

The noise generated by the energy source within the ballast is transmitted to the fixture by mechanical vibration of the ballast surfaces in contact with the

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Staff Assistant to the Manager of Engineering, Small Apparatus
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ted as a paper at the AIEE Winter General Meeting, New York
January 22-26, 1951.—EDITOR.

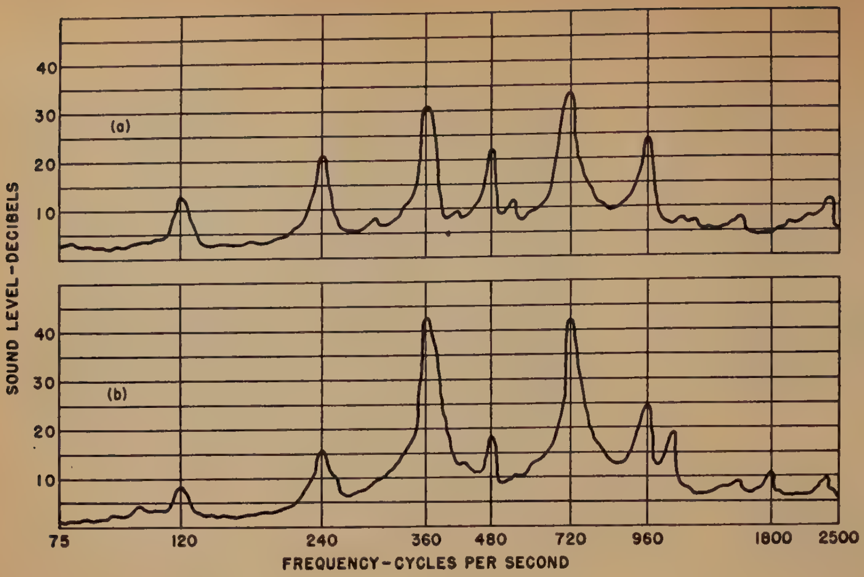
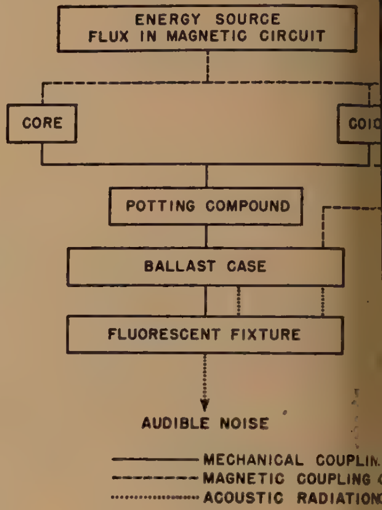


Fig. 2. Typical frequency spectra of fluorescen ballasts
(*a*). Measured noise level =37.0 decibel
(*b*). Measured noise level =46.0 decibel

Fig. 3. Block diagram of the paths for tr sion of ballast noise to the fluorescent lamp



fixture and by air-borne noise which impinges on the fixture surfaces. To evaluate completely the noise characteristics of a fluorescent ballast, both components which contribute to fixture noise must be considered. If any great progress in noise reduction is to be made, a method of measurement which will evaluate these components certainly is indispensable.

EARLY MEASUREMENT SYSTEMS

Early noise evaluation was made by listening to the ballast alone in a low noise-level area. The ballast was placed on a felt pad in a quiet room (Fig. 4). A quick-acting switch later was incorporated so that two ballasts could be operated on the same lamps, one at a time. By means of the switch, the lamps could be transferred from one ballast to the other. In this way, comparison was much easier. However, this method evaluated only the air-borne noise, and correlation with actual performance in a fixture was poor.

Some work was done by listening with a stethoscope (Fig.5), which enabled the observer to place the probe of the stethoscope at various points on the ballast and then compare the vibration of one ballast against vi tion of another. Experience has shown that the vi tion of the ballast surface varies considerably from point in the surface as compared with another pc The location and severity of vibration varies consi ably from ballast to ballast, even of the same des Therefore, a systematic and laborious comparisor many points on two ballasts under study would required. The observer then would be forced to m an over-all guess as to comparable quality after revi ing those comparisons and making some sort of me integration of the over-all results for each ballast. proved unsatisfactory, because the only way to evalu an unknown unit was to compare it with some stanc for audible noise and surface vibration, as descri

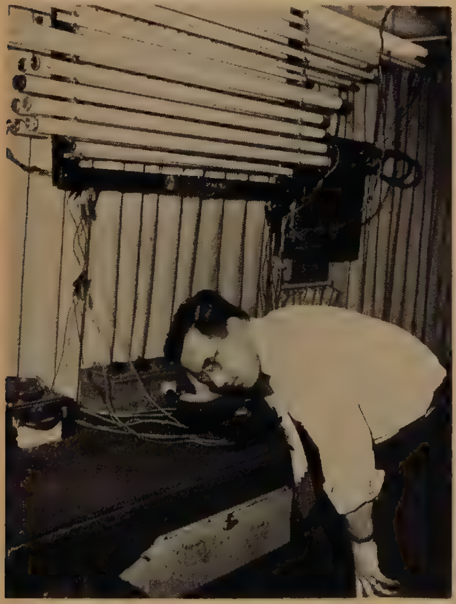
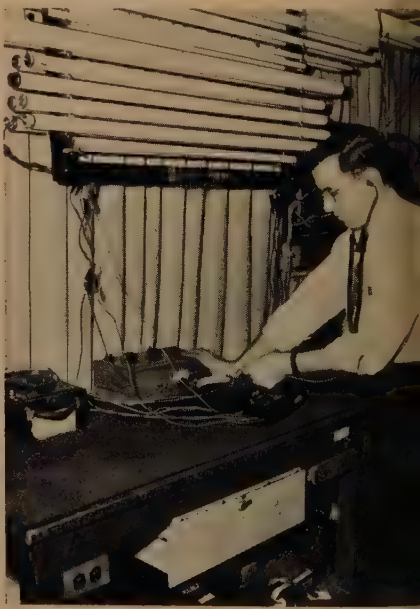


Fig. 4. Ear listening test used to evaluate fluorescent ballast noise

Fig. 5. Listening test incorporating the use of stethoscope



6. Concrete noise tunnel

th nothing better available, this system was used valuate development samples, results of design ges to reduce noise, and as a spot check on pro- on. It was subject to numerous disadvantages:

. The system was subject to the frailties of one pair human ears per observer. For practical purposes, s meant one pair of ears for many tests, although important comparisons more observers were used.

. An observer is influenced by fatigue. After dying a few ballasts intently, he becomes nervous l doubtful of his own ears. He can rarely do con- ent work for more than five or ten units at one iod. If more units are tried, he will not be able repeat results unless differences are very great.

. The system still had no numerical basis which ld be repeated with any degree of accuracy.

The method was laborious, slow, and ex- sive.

As mentioned previously, it did not correlate ticularly well with field experience.

l-level Meter

e next approach to this problem was to measure oise of the ballast with a sound-level meter. A ard sound meter was used, with the standard 40- el weighted network, which discounts the high and low frequencies by about the same amount as the human ear for this level. The sound-meter pickup was placed at various distances from the ballast in an attempt to get a reading that would represent ballast noise. With extremely low-noise-level surroundings—18 to 20 decibels—it was necessary to bring the pickup within one inch of the ballast to get readings high enough above the prevailing noise level of the room to provide reliable readings, about 22 decibels. This is far less noise than that normally generated by many other electromagnetic devices which have become more or less accepted. There is some indication that the ballast-noise acceptance level for most users is increasing, but it is far below that of most other electromagnetic equipment for the reasons outlined earlier, the major one being that light sources have been essentially noiseless for many years.

The method of direct noise measurement was not entirely satisfactory but, for the first time, numerical values of noise could be determined. For these measurements to be of any value, the noise had to be measured at numerous points over the ballast surface, and a weighted average had to be used; that is, it was recognized that noise emanating from the mounting areas and those surfaces likely to be in contact with fixture surfaces would result more readily in a noisy fixture than the noise originating from other surfaces of the ballast.

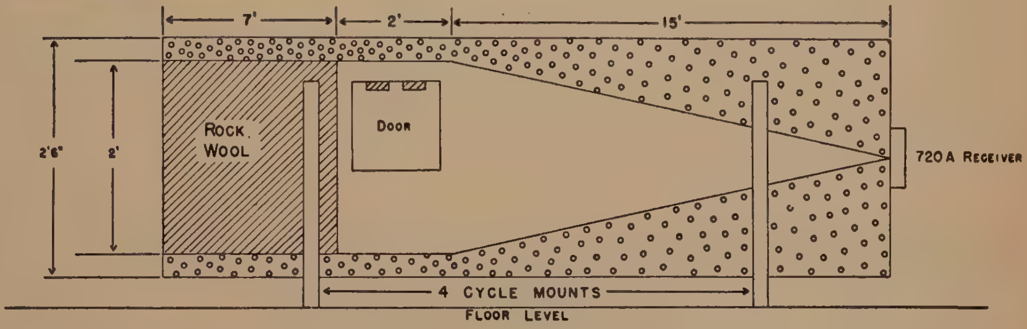


Fig. 7. Cross section of concrete noise tunnel

In the early work, four readings on the side opposite the mounting surface and four readings on the mounting surface were used to describe the unit. No definite weighting scheme for the various readings was developed, because the system had other shortcomings which resulted in its discontinuance before such refinements could be made. These shortcomings were:

(1). Quiet ballast could not be measured reliably even in an 18-decibel room with the pickup at one inch.

(2). There were many indications that results of this method could not correlate reliably with actual listening tests on the ballasts when installed in representative fixtures.

(3). Considerable error could be introduced from small variations in setup, because the distance from ballast surface to sound-meter pickup was small.

Concrete Horn

A device for amplification of readings was made by building a long concrete tunnel, which is shown in FIG. 6. A cross-section of the tunnel is shown in FIG. 7.

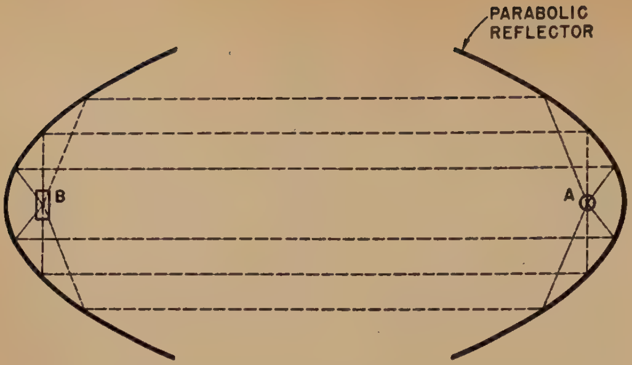


Fig. 8. Parabolic reflector scheme of ballast noise measurement
A: Sound meter pickup at focal point of parabolic reflector
B: Ballast at focal point of the other parabolic reflector

The length allows flat frequency response down to about 60 cycles. The ballast is inserted through the door near the large end of the horn. The rock wool absorbs all sound emanating in that direction, and the pickup at the small diameter collects noise emanating from the surface of the ballast facing the pickup. The entire structure is isolated by flexible mounts from the supporting floor. The heavy concrete walls greatly reduce the noise inside the tunnel caused by outside noise level. A very high-gain amplifier was used, and this device is still useful for certain engineering studies, but is subject to the same lack of correlation with fixture performance as the listening tests and the air-borne sound tests.

Parabolic Sound Reflectors

Another method which has been used is to place the ballast at the focal point of a parabolic reflector several feet in diameter. An identical reflector is placed some distance away, and the sound-meter pickup is placed at the focal point of the second parabolic reflector (Fig. 8). This method probably was fairly successful in integrating the noise emanating from one area o ballast. However, it had to be used in a quiet loca Results were not satisfactory. Thus, it becam creasingly evident that some method of test necessary that would:

(1). Amplify the ballast air-borne noise and surface vibration in a manner similar to an a fixture, dealing in both of these components.

(2). Produce repeatable readings to as high a de of accuracy as possible.

(3). Evaluate a ballast with a single number w would be a fair representation of its performanc an actual fixture; or place various ballasts in pr quality order as corroborated by listening test various commercially available fixtures.

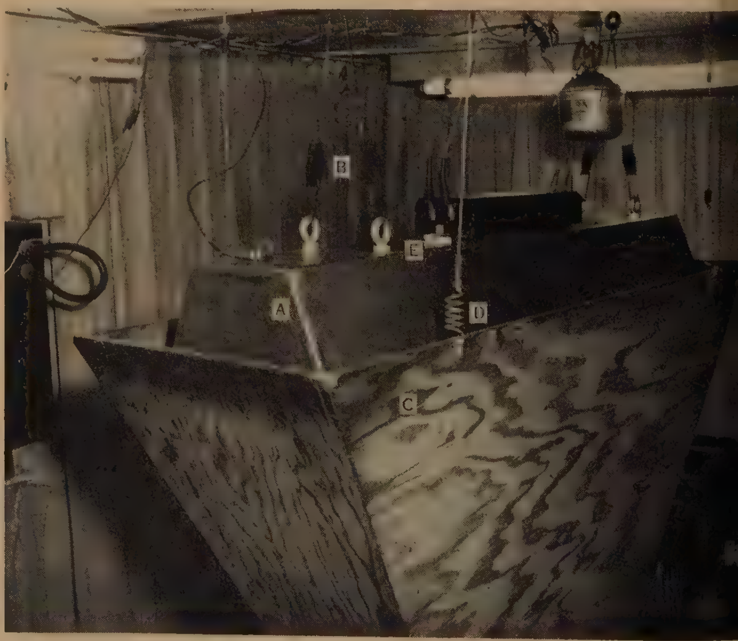
PRESENT MEASUREMENT SYSTEM

Dummy Fixture

The present measurement system used by the aut appears to be a fairly good answer to the requireme It has been in use for about two years, and has ha number of modifications and refinements during early part of that period. It is described here in hope that others interested in this problem can use evaluate it, criticize it, improve it, and then perh accept it as the basis for an industry-wide metho noise evaluation.

The system consists of a special dummy fixture Fig. 9, approximately 4 ft long and suspended by lating mountings *B*. A collecting horn *C* is placed be the fixture by other independent isolating mounts The horn collects noise emanating in a downward di tion from the fixture and carries it to a standard sou meter pickup. The ballast to be tested is placed on horizontal surface by special mounts *E*. These mou

Fig. 9. Ballast and noise test assembly showing relative positions of ballast, fixture, horn, and sound-level meter



adjusted for a particular ballast size, and subse-
mounting of these ballasts is a rapid and con-
operation.

primary purpose of developing a ballast-noise
rement system was to obtain a realistic noise-
y number which would define the noise charac-
c of any ballast. This test was designed to be a
rd noise test for all fluorescent ballasts. In order
eadings for today, tomorrow, next week, and next
ould be compared, all variables except the ballast
had to be investigated and carefully controlled.
first variable to be controlled or to be defined
e noise-test fixture on which the ballast was to
ounted. Commercial fixtures vary greatly in design
mechanical construction so that it seemed almost
ssible to select a representative "standard" fixture
is test. Because the ballast would be mounted in
ixture for the noise test, an open-type fixture ap-
d to be the most suitable for this application. Most
nercial fixtures completely enclose the ballast in a
nel, so that the louvers or glass, lamps, and reflector
be removed to remove or mount the ballast. The
required for such a procedure was considered pro-
ive in a noise-test fixture to be used for evaluating
oise characteristics of fluorescent-lamp ballasts.

mmercial fixtures vary in length from approxi-
y 20 in. for the 15-watt lamp to 100 in. for the
. slimline lamps, so that some compromise in
h also was necessary. Ballasts vary in length from
t 2 in. to 20 in.; thus it was decided to use a 48-
xture, because this length of fixture is widely used
-watt fluorescent lighting.

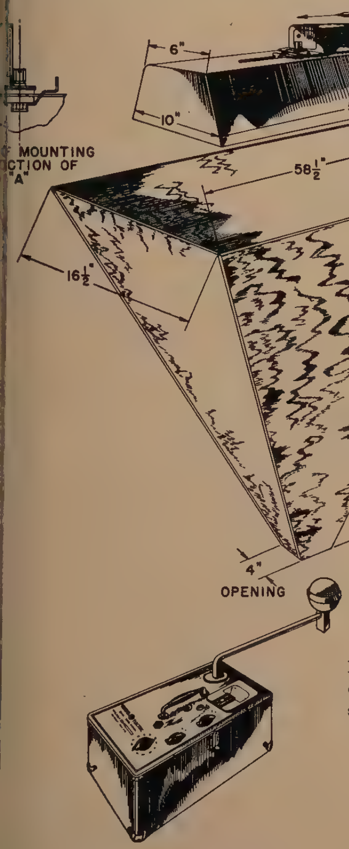


Fig. 10. Construction details of the ballast-noise-test assembly

Mounting

Fluorescent ballasts normally are either mounted flush to the surface of the fixture or on embossed sections at the mountings. The flush mounting was subject to additional variables because of the irregularities both in the mounting surfaces of the ballast and in the fixture. Thus, it was necessary to select a method of mounting which would couple the ballast to the fixture without introducing variables in the mounting.

Extensive testing with the fluorescent-lamp ballast mounted flush to the fixture with spring clamps indicated that large variations in ballast noise resulted from the irregularities in the mounting surface and the spring clamps. To eliminate these variables, the fluorescent ballast was spaced up $\frac{3}{16}$ in. off the fixture surface on a square lock nut with a circular mounting surface one inch in diameter. This assembly is shown in Fig. 10, with the ballast mounted in position for noise test.

Test Lamps

The fluorescent lamp, which is the load for the ballast, was subject to variations which also affected ballast noise. Noise tests conducted with new lamps (seasoned for 200 hr) and old lamps (near end of life) indicated that the noise level of the 40-watt ballast would be approximately two decibels higher with lamps which were near end of life. The fluorescent lamps used in this aging study were taken from the same lot of lamps.

It has been observed also that, as a fluorescent lamp warms up to its operating temperature and lamp watts become stable, the ballast-noise level also becomes stabilized. The relationship between the warm-up of various lamps and ballast noise is plotted in Fig. 11. The curves plotted in Fig. 11 were taken with three lamps of different size and rating, to show the change in ballast-noise level as the fluorescent lamp warms up.

The errors encountered due to the age and temperature of the fluorescent lamps are not excessive, but these variations were particularly undesirable whenever ballasts were tested during this warm-up period or after a change in lamps. To avoid these variables, the lamps are replaced periodically, and a 30-min. minimum lamp warm-up period is required before starting any ballast-noise test.

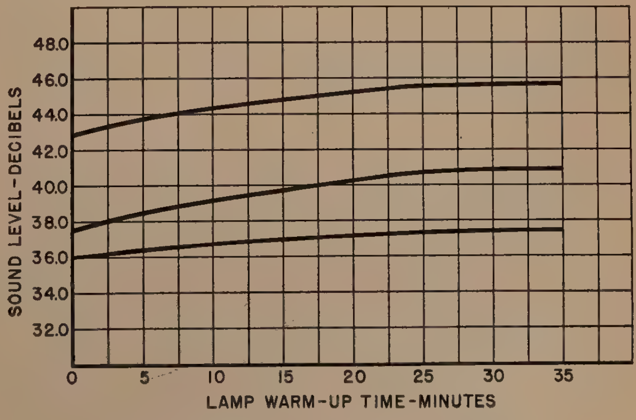


Fig. 11. Lamp warm-up time vs. ballast-noise level

The mounting of the fluorescent test lamps also presented a problem, because it was impractical to design a separate ballast-noise-test fixture for each length of lamp. To simplify the test setup, the fluorescent lamps were removed physically from the test fixture with circuits available for selecting any desired fluorescent lamp and ballast combination.

The test circuit is so wired that the test lamps are operated continuously by a stand-by or auxiliary ballast, except during the actual time when the lamp load is switched to the ballast on the noise-test fixture. This circuit is described in detail in FIG. 12. With such an arrangement, it is possible to keep the lamps at a normal burning temperature during the intervals between individual test readings. The test lamps are mounted horizontally in the sound room, but the auxiliary ballasts are mounted outside, so that they will not contribute to any increase in room noise.

Temperature Conditioning

In testing ballasts for developmental and production quality studies, it was soon realized that the temperature of the ballast also affected the recorded ballast-noise level. Fluorescent ballasts in general do not generate the same amplitude of noise at room temperature as they do at elevated temperatures, so that the ballasts must be compared at the same temperature, to obtain repeatable noise data.

The most consistent results have been obtained with the ballast conditioned in a 65 C ambient for a minimum period of 4 hr and a maximum of approximately 24 hr. The ballasts are conditioned in their normal operating position during this period, with the base of the ballast up. It is noted that in some installations the ballast may possibly be mounted base down; but the base-up conditioning eliminated most of the shifting of the core and coil in the warm potting compound during the conditioning period.

It also is admitted that the user of the fluorescent ballast will hear the ballast first at room temperature; but, as the ballast temperature rises because of core and copper losses, the ballast will attain a "hot" condition. This variation of ballast noise with temperature is illustrated in FIG. 13. The fluorescent ballast, to have an acceptable noise characteristic, must be quiet both hot and cold. But, for the study of the effect of treatments, potting materials, core designs, and manufacturing technique on ballast noise, the hot condition generally is the most critical and most suitable for these evaluations.

General Factors

The purpose of controlling the variables described is to make possible a reliable, repeatable ballast-noise test. The variables described in the measurement of ballast noise do not produce noisy ballasts but, if uncontrolled in this test, individual ballast-noise levels would be almost without value. These controls are extremely important in making decisions in ballast design which will insure a quieter fluorescent-lamp ballast.

In the adoption of a noise-test fixture, it was rea
that this fixture definitely would have a resonant
quency in the audio range near the fundamental o
of the many harmonics of the noise generated by
ballast.

The noise-test fixture shown in FIG. 10 has a reso
frequency of approximately 100 cps. This resonant
quency has proved low enough to prevent errors
result of fixture resonance. The gain of the combina
of fixture and horn is approximately 12 decibels.

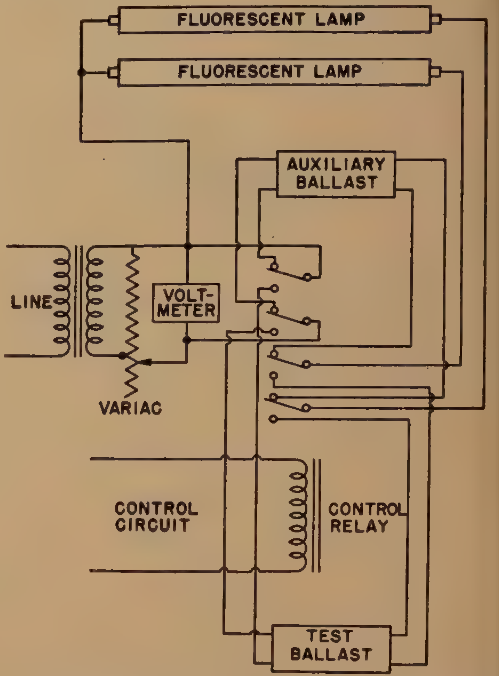


Fig. 12. Circuit diagram of connections for ballast-noise test with auxiliary ballast

is the gain in ballast-noise level above the intensit
noise detected at one inch from the mounting surf
of the ballast.

Frequency spectra of ballast noise as measured
one inch in air may be compared with the noise am
fied in the test fixture (FIG. 2). Such a compari
indicates that the dummy fixture produces a faith
amplification of the ballast noise. The ballast-noise-
assembly responds to both the air-borne and vibrati
borne (mechanical coupling) components of bal
noise. As explained previously, this type of test is
desirable than a measurement of only the air-bo
component of ballast noise. This noise-test fixture
been proved more critical of ballast noise than
available commercial fluorescent fixture.

Calibration

Several methods have been investigated for cali
tion of this ballast-noise-measurement system, suc
magnetic standards, standard ballasts, and air
The magnetic sources have not proved stable eno
for calibrating the fixture, and the air jet does not
erate sufficient fixture vibration for calibration.
air-borne noise generated by the rush of air through
air jet can be used for calibrating the sound mete

st assembly, but a nonpitched acoustic calibrator h more suitable for this purpose. The sound-level is calibrated before each test period.

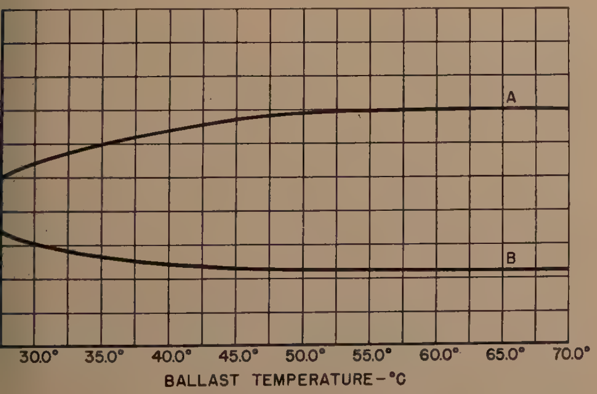
day-to-day variation in the sound-level meter has xceeded more than 0.5 decibel; thus errors in und meter are at a minimum. The fixture setup, ing horn, sound meter, and ballast mounting, is d carefully before each test period. Specially pre- ballasts are used to check the gain of the equip- to maintain close control on the entire ballast- test.

control of the variables in fluorescent test lamps, ts, and noise-test assembly has made possible a rison of ballast-noise data on designs built today hose assembled in the past or those to be assem- n the future. Listening tests are not employed for ive measurement of noise; but they do aid in ating noise data with the response of the human Data received from the many installations in the rovide a very important and helpful evaluation customers' response to the ballast noise measured laboratory and the factory.

cations

ballast-noise test described in this report has had l important applications. One of the most valu- as been as a tool for evaluating possible methods ducing ballast noise. This has included evalua- of various ballast cements, treatments, potting ods, core designs, and production-assembly meth- To make a change in process or design without ng its effect on noise would result in expensive y trials and possible complaints, if the change l be unsuccessful.

se-study trials on a small sample basis are possible this noise test, to evaluate the effect of the pro- change in methods or design. After any change roved successful on a sample basis, it can be l in production with confidence that a noise re- on will be realized. Some changes may result in small reductions in noise level, but an accumula- f such changes can result in noise reductions which ery significant. The noise test has made possible a lete noise evaluation of many ballast designs before allast ever reached the regular production floor.



3. Curves of ballast temperature vs. ballast-noise level. Curves B are typical for ballasts with increasing and decreasing char- stics

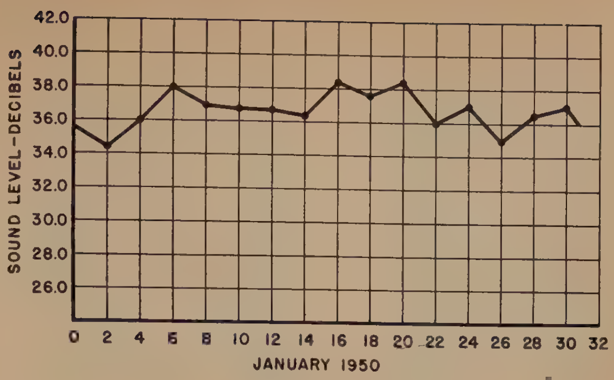


Fig. 14. Variation in ballast-noise level as indicated by quality-noise tests

This noise test also can be used in maintaining a close watch on the noise quality of the ballast shipped to the customer. It is not, however, suitable for a 100 percent check on all ballasts shipped to the customer. As stated previously, this test is too lengthy and would be too expensive for such a purpose. A quality sampling of ballasts from the production line is possible, however, and it has proved useful in detecting and correcting any tendency toward increase in noise level of production units (FIG. 14).

Production Testing

Noise ambients on the production line range from 70 to 80 decibels, so that it is not practical to attempt to obtain the 20-decibel noise ambient recorded in the sound room. Because such ambients can not be obtained easily on the production floor, some other system must be employed for the production noise test: The 100 percent production noise test is not impossible, and two promising methods are available. The primary requirement of any method for production testing noise is that it must reject all ballasts above an established, acceptable limit for ballast noise. This limit may be established either to control the over-all noise level of ballast installations or merely to reject only the ballasts with extremely high noise levels (buzzers).

Testing experience has proved that a ballast which is considered objectionable in a fluorescent fixture also will have a high component of air-borne noise. Construction of a sound box for detecting extremely high noise levels is possible even for use on the factory floor with a 70- to 80-decibel ambient. This sound box is assembled by placing one box or more within another, acoustically isolated, so as to obtain about a 50-decibel ambient. A measurement then is made of the air-borne component of ballast noise, with buzzers producing readings as high as 70 decibels.

Another system which is even more suited for production testing is a measurement of ballast vibration. Close correlation has been found not only between objectionable ballast noise and the airborne component, but also between ballast noise and case vibration. Early tests indicated that little correlation exists between the over-all ballast-noise level and ballast vibration measured over small areas, so that a single-point measurement of vibration is not satisfactory for noise testing. Measurement of vibration over a relatively large area of the ballast-mounting surface does, however, correlate with ballast noise.

This test can be simply accomplished by the use of several (crystal) vibration pickups or by using a single-contact microphone attached to a special mounting plate. Thus, with the ballast excited while in contact with the vibration pickups or mounting plate, the relative amplitude of the measured vibration correlates with fixture-noise levels. By properly isolating the crystal pickups from external vibration, it is possible to obtain relatively low ambients, making this test suitable for production noise testing.

It is to be noted that whatever system may be employed on the production line, that system must separate the "good" from the "bad." This means that, first of all, some absolute system of noise measurement is needed to determine acceptable noise levels and to maintain a continuous check on the production-noise test. Without a standard ballast-noise test, no correlation can be expected among the many systems employed to determine acceptable noise levels or to define a "quiet" ballast.

Conclusions

The system for the measurement of ballast noise described in this article has proved reliable in comparing the noise levels of the many fluorescent ballasts manufactured today. Experience with this test equipment indicates that, with the variables of mounting, heating, and fluorescent lamps closely controlled, it is possible to obtain reproducible noise data. The data obtained are not only reproducible but also correlate with actual noise tests on commercial fluorescent fixtures.

The noise levels recorded with test equipment can be used to advantage in rating ballasts from the various ballast manufacturers. Such a rating is illustrated in Fig. 15. The limit for acceptable ballast-noise level shown at 40 decibels will not hold true for all installations; but it is representative of what generally will be acceptable for most users of fluorescent lighting. These readings were recorded with a sound-level meter using the 40-decibel weighting network. It is recognized that some ballasts have different frequency characteris but field experience has indicated that these m ratings are usually true. With the rapid changes ballast design and manufacturing technique, it is ho that a much lower limit can be established in the r future.

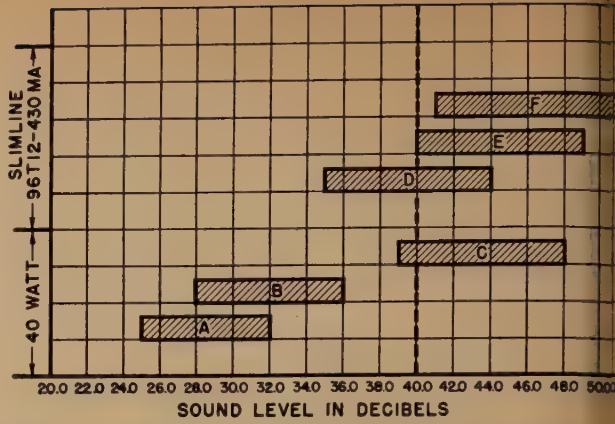


Fig. 15. Typical noise rating of various fluorescent lamp ballasts

The noise-measuring system as presented in article is by no means complete. It is hoped that oth will try this system, perhaps to discover further poss improvements. It is believed that this measuring tem has been developed far enough to be considered others who are concerned with the problems of bal noise and its measurement. During the past few ye the user of fluorescent lighting has become very c scious of the existence of ballast noise. He does accept noise willingly as a necessary part of fluoresc lighting. This undesirable characteristic must be el inated as soon as possible, if the fluorescent lamp is be completely acceptable for all lighting applicati

Acknowledgement

The authors wish to acknowledge the assistance Dr. R. O. Fehr, C. M. Summers, and S. A. Zimmern of the General Electric Company, and the Armour search Foundation of Illinois Institute of Technolo Chicago, Ill.

Reference

"Noise Measurement," *Z24.2-1942*, American Standards A ciation (New York, N. Y.), 1942.

HIGH LIGHTS AND SIDE LIGHTS

Double-quick Motor Production

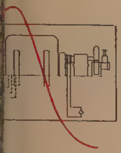
In the face of a rapidly increasing water demand in Nashville (Tenn.), a demand now approaching the maximum capacity of the city's main pumping station, a 1750-hp pumping motor was recently completed in approximately five months. The motor is to be installed in the pumping station during the summer. Under present conditions of material shortage, the time for building such a motor is ten to twelve months.

Designed to increase the station's maximum output of treated water from 40,000,000 gallons per day to 60,000,000 gallons, the motor is part of an order from the City of Nashville for electric equipment which will increase the Nashville water supply by 25 percent. The other equipment, to be installed by next year, will include six other pumping motors totaling almost 10,000 hp.

The principal item of machinery to be replaced in the modernization program is a massive 94-ft-high steam engine, installed in 1907. In its place will be installed a 2250-hp motor less than seven feet high. Other pump motors ranging in size from 600 to 2000 hp will replace steam turbines.

TS FOR TURBINE GENERATOR PERFORMANCE

for turbine generator performance provide
ner assurance of good operation and also yield
or evaluating new developments and for setting
specifications at optimum performance levels



J. Y. Jackson C B Fontaine

By J. Y. JACKSON and C. B. FONTAINE
Generator Engineering Division
Lynn River Works, General Electric Company

ALL large rotating machines, on the basis of xpected performance, the turbine-generator is in by itself. Efficiency is of prime importance—the fuel consumed each year is usually greater than hole cost of the turbine-generator set. Extreme lity is essential—many generators are required to e for months, often a year or more, without a wn of any kind. Industry runs on electric power rruptions may be tremendously costly.

se factors make generator performance of pri- oncern to both the user and the designer. Many tor performance quantities are, therefore, subject rantees—for example, efficiency, winding tem- re rises, and stability. These guarantees place emphasis on those quantities which can be ined directly by test.

rantees of performance have been common to all of equipment over the years. In general, such tees have taken one of three forms:

A guarantee of average performance of a large ber of units, letting the good ones offset the bad . This has sometimes been the practice on very ll apparatus

A guarantee made with a tolerance which may ay not involve a penalty or bonus for departure the exact guarantees. This is a common Euro- practice

A firm guarantee in which the manufacturer s all necessary steps to see that the individual fully meets its specified guarantees.

rantees of performance for General Electric e-generators are on a firm basis. Because of the e importance of generator performance, this is ered the only logical basis for making guarantees. set must individually meet its guarantees.

this emphasis on performance, such a policy he designer inevitably to the following approach:

The procurement of really fine equipment for ng generators

Making with this equipment a large number of rate tests, backed up by analytical design studies, whereby good formulas for predicting performance may be determined, and new developments evaluated (3). Designing the machines with the best balance of cost, efficiency, and other controllable factors, to give the customer the greatest possible value and assurance of quality.

The remainder of this article concerns the means used for controlling and testing the performance of 3600-rpm turbine generators rated 2000 kw to 20,000 kw at the Lynn River Works of the General Electric Company. The test equipment is described, and statistical uses of test data to arrive at optimum generator design are presented.

Tests on turbine generators fall logically into two categories: (1) no-load tests and (2) rated-load tests. No-load testing has an important place in connection with turbine generators, because component losses can best be measured in this manner. Also, certain characteristics, such as ventilating air flow, can be measured as accurately at no load as at full load. On the other hand, heating of windings and core parts for machines of this size range can be determined more accurately by testing under actual load conditions than by compromise no-load testing. A judicious use of both no-load and full-load testing is necessary.

No-load Test Equipment

Assurance that a generator meets the performance required of it is of prime importance to the user and to the designer. Such assurance is given the user, for many performance characteristics, by electrically testing each generator on the dynamometer test stand shown on the COVER.

By assembling the generator on adjustable parallels and driving it with a d-c dynamometer, no-load electrical tests and loss measurements are obtained. Additional facilities are built into the base of the test equipment for measuring air flow and fan characteristics of generators selected as representative of a given rating.

Three adjustable bases of different sizes are provided. This is done because the variety of sizes of generators would complicate the design of a single base to fit all

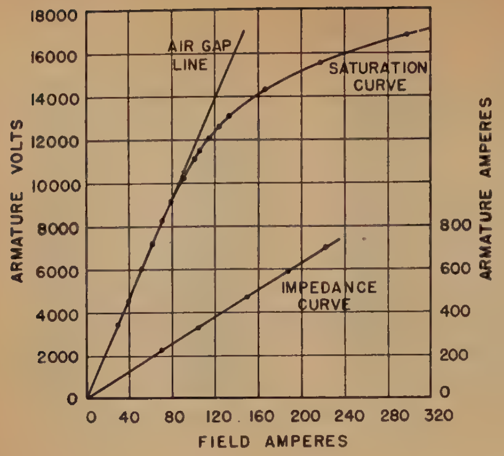


Fig. 1. Test saturation and impedance curves, taken at rated speed

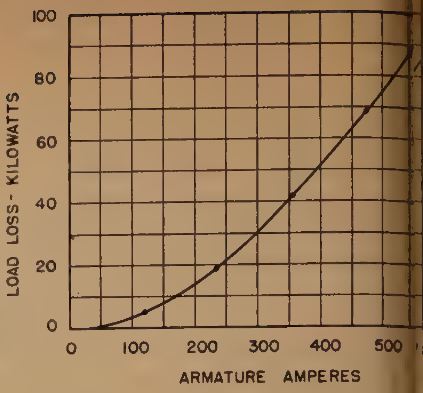
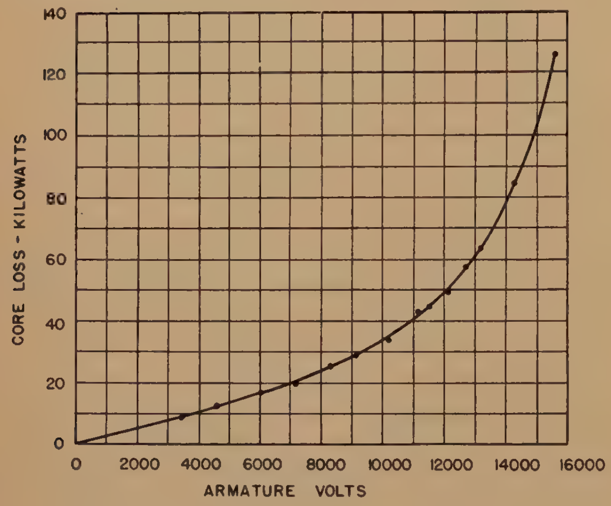


Fig. 3. Variation of short-circuit load loss with armature current, tested at rated speed

Fig. 2. Variation of open-circuit core loss with armature voltage, tested at rated speed



size generators, and because the dynamometers can measure torque more accurately when loaded to values near the upper limit of their capacity. This base arrangement holds alignment time to a minimum and allows accurate measurement of losses.

No-load Testing

Assembly

The base is arranged to accommodate the production machine in advance of the date the machine is scheduled for test. The generator stator, with the field resting in the bore, is lifted onto the base by overhead crane; the rotor with a previously assembled stub shaft is aligned with the dynamometer; the flexible coupling between the dynamometer and the stub shaft bolted in place; and the stator lined up with the rotor to obtain the correct air gap. The flexibility of the base reduces alignment time to a minimum, which aids in minimizing the length of time required to test a machine.

Resistance Measurements

As a preliminary check on manufacture and design of a generator, the resistance of the field and armature is taken and compared with calculated design values. At this time the embedded resistance temperature tectors are checked for accuracy against a calibra mercury thermometer. If these checks are within prescribed limits, preliminary balancing is started.

Balance, Field Bake, and High-speed Run

Mechanical reliability is vital to the operation turbine-generator and the obtaining of this virtue quires that the generator operate at rated speed negligible shaft vibration. Because of the nature insulating, forming, installing, and blocking field into position in a rotor of large diameter, the fie when manufactured, may be unbalanced. Elimina of this unbalance is the first step toward operatin generator at rated speed. It should be noted here t although a generator rotor weighs several tons, ultimate balance is so fine that it must be accomplis by the correct placement of balancing weights weigh about one ounce.

Balancing can be accomplished very quickly on test stand because of the rapid accleration and dece ation made possible by the dynamometer drives and use of special balancing instruments to locate the rect positions for the balancing weights. After a liminary balance which allows the rotor to be run t percent above rated speed, a field bake and high-sp run is made. Centrifugal forces exhibited when a fiel run at rated speed may cause coils and blocking to m radially outward toward the wedges and retai rings. A good balance requires that these coils, ins tion, and blocking stay in one position. This is acc plished by slowly and uniformly heating a genera field to a temperature at which the insulating mate are semi-plastic, and then cooling the field while run at a ten percent overspeed. Such an opera allows the coils to take a permanent position such no change of radial position will take place normal operating conditions. When the overspeed r completed, a final balance is made and the generat ready for electrical tests.

Electrical Tests and Losses

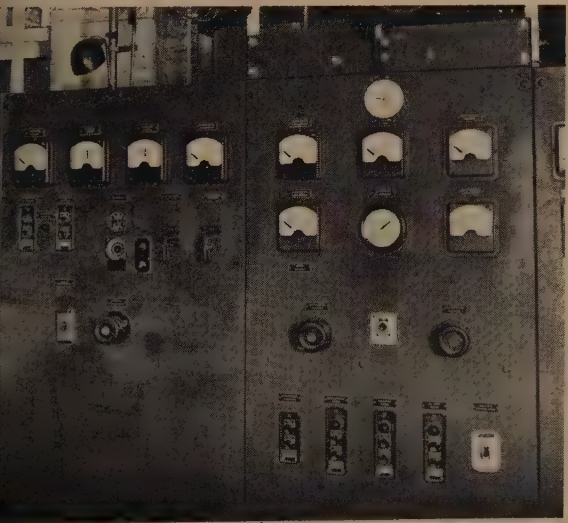
The extreme importance of electrical characteri and losses to the performance of a generator req that saturation and impedance curves be taken on generator. Loss measurements are also taken du these tests. A typical saturation and impedance c n in FIG. 1. A curve showing variation of open-core loss with voltage is shown in FIG. 2. FIG. 3 similar variation of short-circuit load loss with .

n a generator is assembled, permanent leads are ed to the terminals, and calibrated potential rent transformers are installed. All breaker and ntrols are mounted on the panel board as shown 4. Instrument transformer leads are permanently d and connected to jacks on the control panel. ctrical readings are taken with calibrated in- nts connected to the panel jacks.

generators are driven by permanently installed ometers which are supplied direct current by synchronous motor-generator sets. A Ward- d system allows accurate control of the dyna- ers over their full range of speed. Vernier adjust- of speed are made with a dynamometer field t. Speed is indicated by an electric tachometer ed in the panel above the dynamometer controls. r indications of speed are determined by use of a scopic instrument mounted directly below the eter. This instrument has a slotted rotating disk from the dynamometer tachometer generator, stroboscopic lamp supplied from a constant- ncy signal generator. When the generator field at exactly the desired speed, the disk appears to n this manner speed is regulated with a high of accuracy.

measurements are read each time a point is for the saturation or the impedance curve. These ints are indicated by a scale which is part of the ometer assembly. Losses are accurate to within ent of the dynamometer rating. The relatively losses in the coupling and the dynamometer are cted from the losses as read in order to arrive at s in the generator itself. The data from these loss rements assure the accurate evaluation of no-load

type of base used in these tests allows losses to be red on each generator with practically no increase of testing time. This permits a policy of measuring losses on each generator. This practice would require a prohibitive amount of production time and cost if a special set-up were made for each machine.



Control panels for dynamometer test stand, showing speed and controls for one dynamometer at left and power supply controls three dynamometers at right

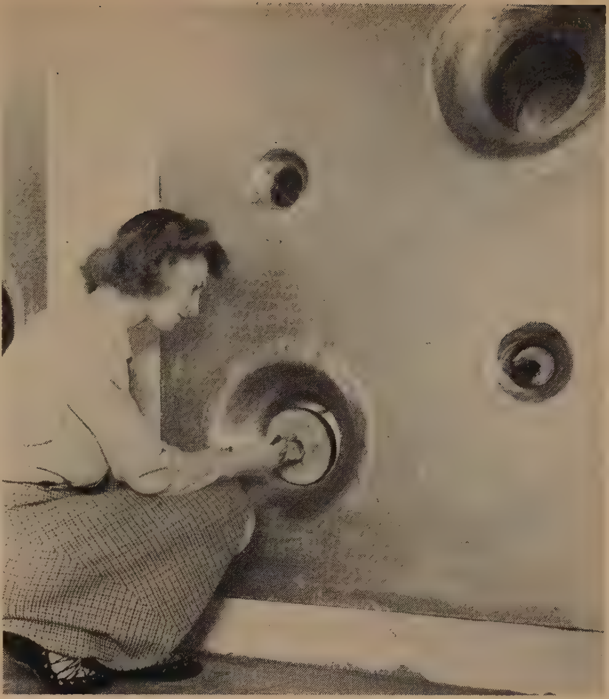


Fig. 5. Plenum chamber, showing orifices for measuring air flow

Other electrical tests that are made on every generator include: measurement of telephone interference factors; measurement of phase sequence; insulation resistance measurements; and high-potential tests.

All of these tests must be approved by the Engineering Division before a generator is removed from the test base. These tests provide a quality-control check on the finished product and at the same time give extremely valuable design information to the designers. The test base has become a valuable production tool and an assurance of quality in the machine as well as a highly valued source of developmental information.

Air-flow and Fan Characteristics

Ventilation of an air-cooled generator requires that a volume of air approximately equal to the generator weight be forced through it each hour. Assurance that a fan will provide the correct quantity of air can be obtained only by tests on the fan running in the generator.

Equipment is provided beneath the dynamometer test stand for taking the desired air-flow tests while the generator is operating at rated speed. The ventilating air from the generator is conducted into a large plenum chamber, and thence through a group of calibrated measuring orifices to an exhaust chamber. The desired pressure is set by a variable-speed blower and a set of adjustable louvers in series with the orifices and located at the exit of the exhaust chamber. A view of some of the measuring orifices in the plenum chamber is shown in FIG. 5. All air pressures, including the drop across the

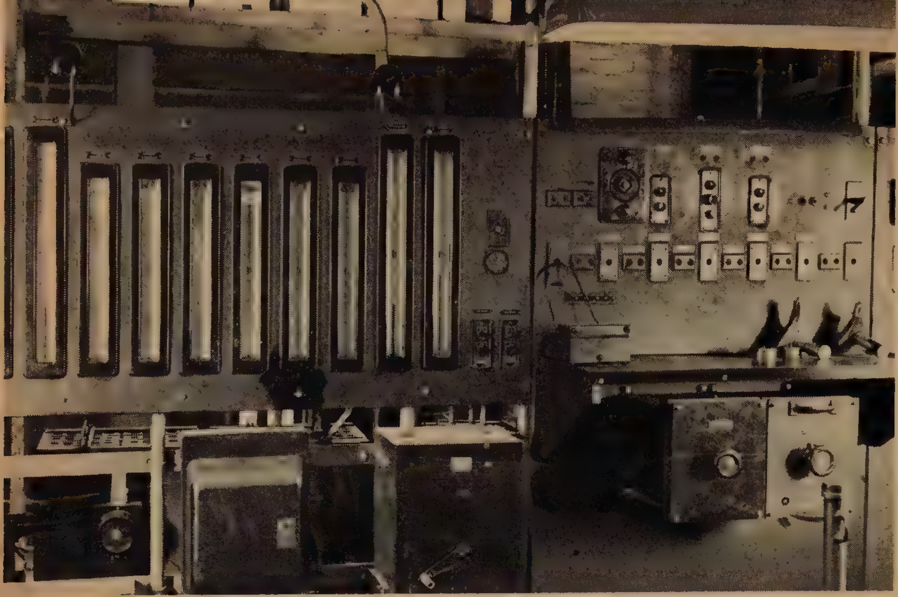
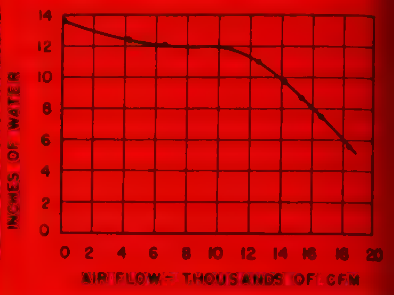


Fig. 6. Ventilation test control panel, showing liqu
nometers for measuring air pressures and flow, and the
for variable-speed blower and adjustable vanes

Fig. 7. Pressure-volume characteristics of gen-
erator fans



orifices, are measured by liquid manometers mounted on the fan control panel shown in Fig. 6.

At the end of the test base an entrance to the plenum chamber is provided where developmental fans are tested by mounting them on a hub driven by a motor. A developmental fan may be tested without disturbing the generators on test. This test is very useful in determining the characteristics of developmental fans, or those needed for unusual generator applications.

This air-flow and fan-test equipment has proved a great asset to the design and manufacture of generators in providing pressure-volume characteristics for all fans used in generators of present design. These data, as well as special developmental tests, have aided in the design of fans for new applications and improvement in generator fan design in general. Fig. 7 shows a typical pressure-volume characteristic of generator fans, measured by test on a completed generator.

Rated-load Test Equipment

Customer requirements for more generating capa
per dollar expended have made imperative the need
more efficient and smaller generators of a given rati
To accomplish these results and still meet rigid te
perature-rise specifications and other considerati
which give assurance of long life, accurate rated-lo
temperature-rise data must be obtained. It is
practical to obtain such data on smaller units in pow
plants, because the load conditions available are gen
ally not steady enough for accurate testing. The id
place to conduct load tests is in the factory. There
generators, particularly those incorporating new
velopments, can be thoroughly and accurately test
with the opportunity to make any desired modificati
before shipment.

Equipment for testing generators at rated load
been installed at the Lynn River Works of the Gene
Electric Company. This facility provides a means

Fig. 8. A 7500-kw generator being tested at full load on load-test base. The generator is shown at the left, the permanent test motor in the center, and the driving turbine at the right

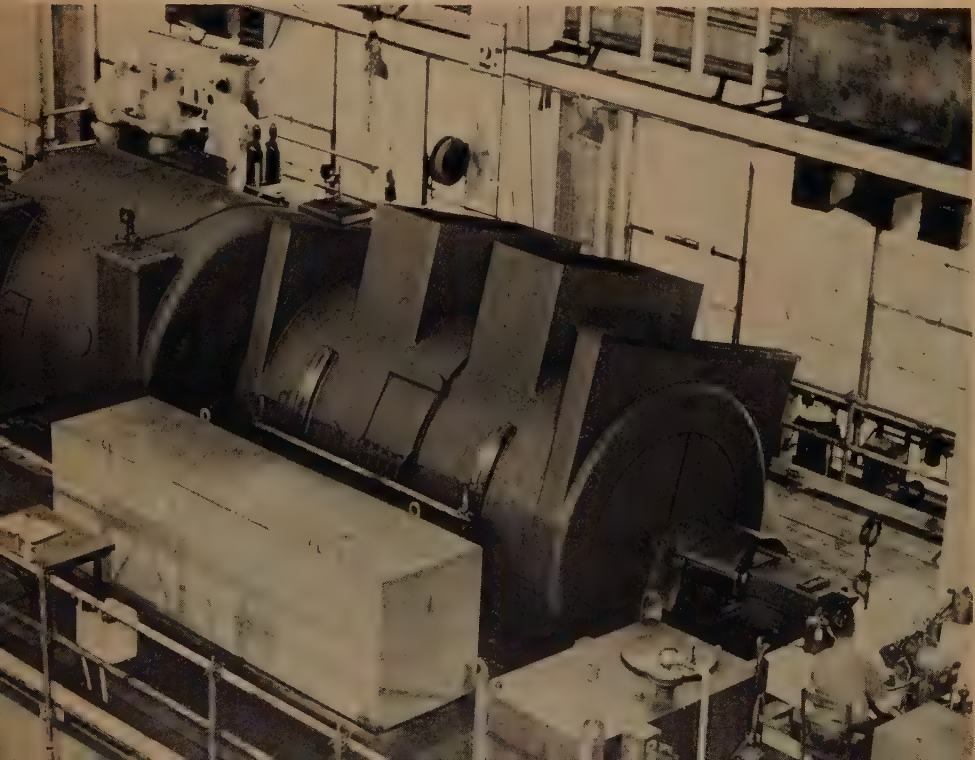
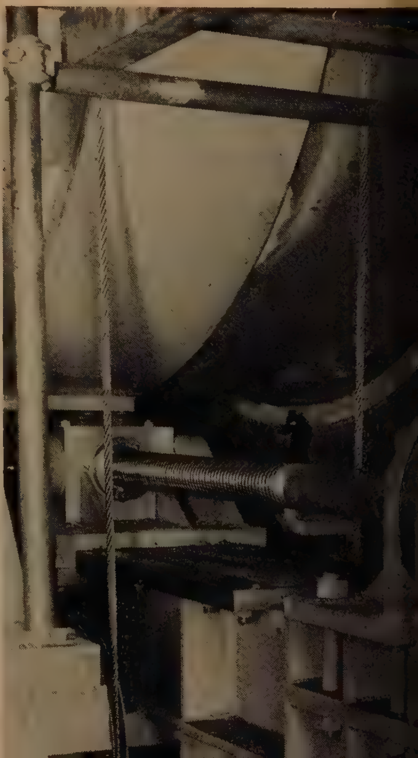


Fig. 9. Turning mechanism for motor stator,
ing driving screw, crosshead, and cradle supports
stator frame



ɔad testing of generators rated 2000 kw to 15,000 pf in the factory with no input other than that d to supply the losses of the generator on test the associated test equipment. FIG. 8 shows a w generator undergoing load tests on the base.

nerator is tested at rated load and power factor necting the generator armature terminals to the re terminals of a motor of adequate size, bolting erator field coupling to the motor field coupling, ving both machines at rated speed with a small e. In operation, the motor is driven at synchro- speed electrically from the terminals of the tor. The generator rotor in turn is driven me- ally by the motor. Losses of both machines are ed by the small turbine.

btain load, a power or load angle must be created h the motor and the generator. This is done by ing the motor stator in a cradle and supplying the ary turning mechanism to rotate the stator through uired load angle. This mechanism is shown in FIG. 9.

complete equipment for load testing, shown atically in FIG. 10, consists of a large synchronous rated 18,750 kva at 1.0 pf permanently mounted adle in which the stator can be turned by a per- tly installed turning mechanism; a small turbine 900 hp permanently coupled to the collector end motor; an adjustable base which will allow any e generator rated 2000 kw to 20,000 kw, 0.8 pf to embled and coupled to the synchronous motor; ixiliaries, such as the torquemeter for measuring the oil system, the control panel, and the cooling- supply.

llustrate the operation of this base, assume that a -kw 0.80-pf 13,800-volt generator is to be tested ed load and power factor. The generator rotor is coupled to the motor rotor with approximately y degrees between the centerlines of the respective After assembly is complete and armatures of achines have been connected, both machines are it to 3600 rpm with the small turbine. Excitation applied to both machines and adjusted to give voltage and the desired power factor. The load is then increased by turning the motor stator holding constant armature voltage by adjusting the field currents. The load angle is increased until the desired load is obtained on the production generator.

Once the motor and generator rotors are coupled, it is not necessary to change the coupling position to test the generator over its whole capability range from zero power factor underexcited to zero power factor overexcited. Necessary changes in load angle are obtained by rotating the motor stator and by changing armature connections and field polarity of the motor and the generator.

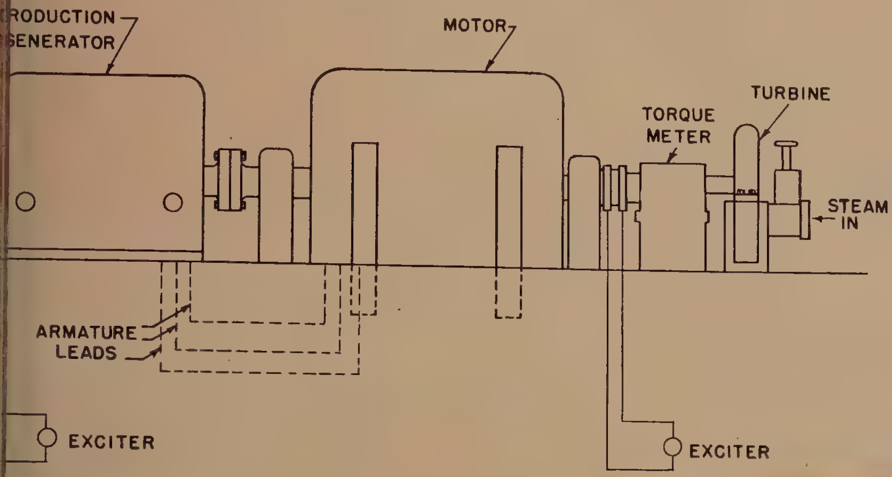
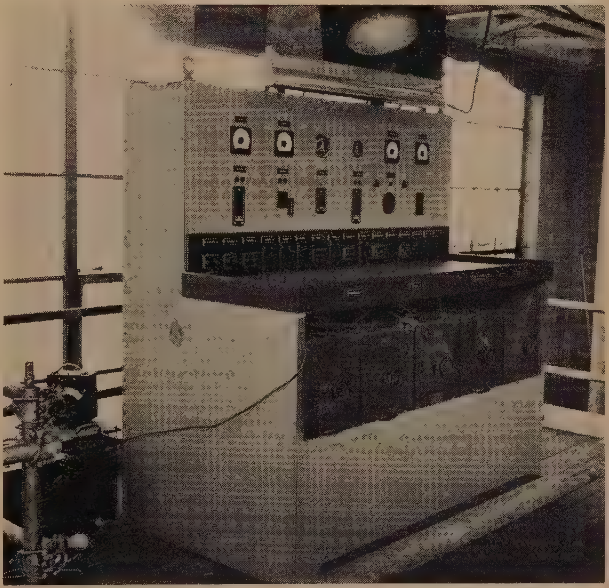


Fig. 10. Schematic drawing of load test base, showing interconnection of units

Fig. 11. Electrical control board for load-test base



Controls

Controls for all electrical equipment are contained in one switchboard, which is shown in FIG. 11. This control panel contains jacks and plugs so that current, voltage, and power transfer measurements may be made at the control panel. Speed is controlled by the governor of the small turbine.

Loss Measurement Equipment

A torquemeter is installed between the turbine and the motor so that the sum of the losses of motor and generator can be determined under load conditions. Losses of the generator on test are found by subtracting the calibrated motor loss from the total. This introduces some inaccuracies, but still yields useful information on generator losses under load.

Load Tests

This base was installed primarily to test generators at rated load and to provide design information on the heating of armature and field windings, which is very difficult to obtain by any other method. In addition, the equipment provides answers to special problems such as end heating at underexcited or leading power-factor operation. This problem is becoming more prevalent as power systems grow larger and require a larger percentage of leading reactive kva when lightly loaded. With this test base, the temperatures of the stator end structures can be determined over the whole range of load power factors from zero lagging (overexcited) to zero leading (underexcited). This permits design of generators with known capability for satisfactory operation in the underexcited region as well as under rated load conditions. The results of such a test are given in FIG. 12. This curve shows the temperature rise of the end clamping fingers of a 7500-kw generator plotted against power factor when the kva output of the generator is held at or near its rated value.

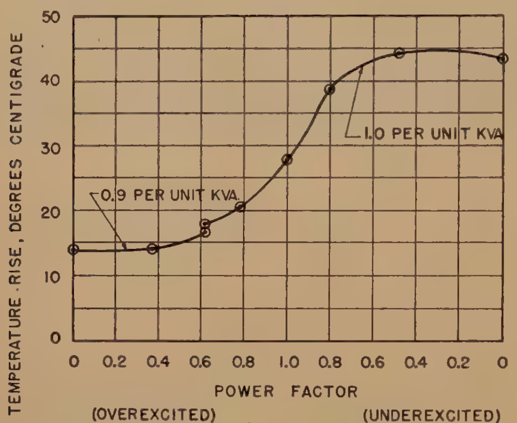


Fig. 12. Heating of stator end fingers, showing variation in temperature rise at constant kva when load power factor is varied

Thus, testing each generator on the dynamometer test stand prior to shipment, and testing selected generators on the rated-load test stand, demonstrates that each generator produced has the mechanical and electrical characteristics required to fulfill the specified service requirements. Such a testing procedure gives the greatest possible assurance of continuous reliable service, low maintenance costs, and long life. In addition, the data accumulated from standard tests and developmental tests made possible by these facilities permit constant improvement of generator design with constant increase in value to the customer.

USE OF TEST DATA TO ACHIEVE BEST DESIGN

Good test facilities do not in themselves assure high-quality products. Of equal importance is the use made of the facilities, not only in performing correct tests, but in evaluating and analyzing test results. The no- load test facilities provide a mass of accurate te formation on losses, ventilating characteristics, s circuit ratio, and other performance quantities. load test facilities offer a smaller number of tests heating and some other quantities. One powerful tional tool is available to the engineer in se optimum designs. That is the use of probability ciples in analyzing the data and setting correct de quantities.

Consider this problem: There are certain cases w the generator designer must guarantee that the sh circuit ratio (SCR)* of the generator when tested not be less than 0.80. Where shall the designer set design or calculated value? 0.80? 0.90? 1.00?

Clearly, the correct figure to be set for the de (calculated) value of SCR is a matter of risk; and greater the margin between guaranteed and calcul SCR the lower the risk of having the test value of fall beneath the guaranteed value. No margin, how great, will eliminate the risk entirely, but the la the margin the lower the risk.

On the other hand, large margins result in a gen tor with lower short-circuit reactances and hig short-circuit currents, a decided disadvantage to customer in providing protective switchgear. weight and cost tend to go up with an increase in sh circuit ratio, and efficiency goes down. (From th would appear that the designer may be limited achieving best over-all design if he is required to gua tee an arbitrarily high value of SCR. This is corr However, there are cases where SCR is guaranteed.)

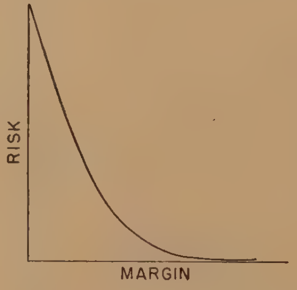


Fig. 13. Basic relationship be margin and risk. The greater the gin, the less the risk of failure to requirements

There are thus compelling reasons why the desi should choose a value of short-circuit ratio (SCR) s that the risk of failing to meet the guarantee wil reasonably low, but such that the margin betw calculated and guaranteed value of SCR will no excessive; in other words, he should choose the nomically correct design value of SCR for that gen tor.

Thus, to answer the question as to the correct v of calculated SCR for the design, two things needed.

First, the relationship between margin and This relationship must be somewhat as shown in 13; that is, the risk decreases as margin increases, never reaches zero.

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*Short-circuit ratio (SCR) is a commonly used quantity relating to g tor stability under steady-state loads, with no voltage regulator oper Specifically, SCR is the ratio of the field current required for normal v on open circuit to the field current required for normal armature curr sustained short circuit.

nd, the correct risk, established entirely from ic considerations. These considerations would the cost of correcting a generator by replacing y other means, the effect on future business of eting a guarantee, etc. One prime consideration he point of view of both designer and user would change in important performance characteris- the margin is changed; characteristics such as ircuit currents, size, cost, efficiency, insulation c.

basic requirement for the engineer in this prob- to establish the relationship between margin sk. This problem can best be solved by the use bability principles.

pply the principles of probability it is necessary ognize that deviations between design calcula- nd tested performance are largely chance varia- These chance variations are related to manufac- tolerances in materials, processes, and dimen- and to unassignable inaccuracies in the calcula- The combination of these numerous chance ions result in what is known as a normal chance ution of the tested performance; the test values metimes greater than average, and sometimes an average.

. 14 shows the characteristics of normal chance ution. In this diagram, deviations from the ge are measured in terms of an index of disper- nown as the standard deviation, indicated by the l σ**.

standard deviation is easily calculated from test It is merely the RMS value of deviations from and average. The greater the number of tests used termine σ, the more accurate the value will be. r more tests should always be used.

. 15 is the normal distribution integral, showing ercent chance that a deviation from average will tside the limits shown. The limits are in terms of σ. Thirty-two (32) percent of all quantities will lie outside $\pm 1\sigma$, 4½ percent outside $\pm 2\sigma$, and 3/10 of one percent outside $\pm 3\sigma$.

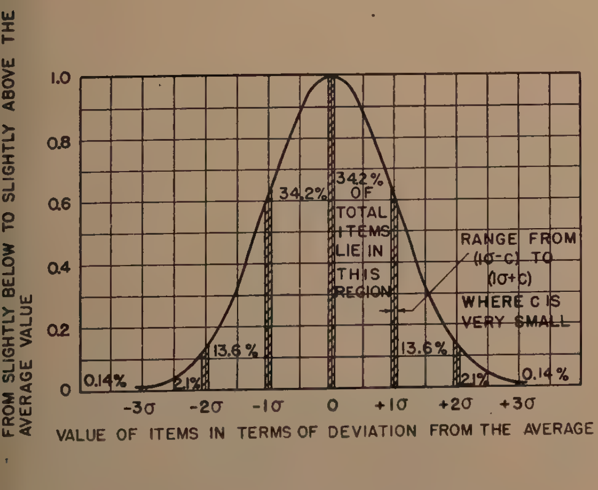

Fig. 14. Probability characteristics of normal distribution

The latter curve is a margin-risk curve such as the designer seeks. If he can determine the standard deviation, and if the individual tests for generator SCR deviate from the calculated value in the manner of normal distribution, then the margin-risk curve expressing the dispersion of individual tests about the calculated value of SCR is defined.

In determining the standard deviation, it is important to examine the things which cause the test SCR of a generator to deviate from the calculated value. These are:

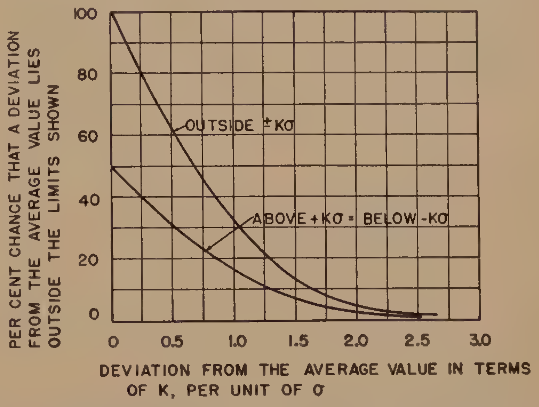

Fig. 15. Normal distribution integral, showing the probability that the value of an item will deviate more than a given amount from the average

(1). Deviations due to manufacturing variations among individual generators of a given design

(2). Deviations due to variations in test measurements

(3). Deviations due to errors in the calculation formulas

The need is to evaluate a standard deviation which combines the effect of all these variations. Test data available to a designer of heavy apparatus (such as turbine-generators) are usually limited. Maximum use is made of available test data, if each test result is put in the form of a Test/Calculated ratio A as follows:

$$A = \frac{\text{Test SCR on one generator}}{\text{Calc. SCR for generators of that design}}$$

If the formulas for SCR are correct on the average, the average value of this ratio, $\overline{X}_A$ is 1.0. The standard deviation of this ratio σ_A includes the effect of variations due to manufacturing and testing, as well as formula errors. Thus the designer can arrive at the quantity he needs—a single standard deviation σ_A which can express the probability of a single test result deviating from the calculated value by a given amount.

This approach can readily be applied to the generator SCR problem. Suppose $\overline{X}_A = 1.0$, and $\sigma_A = 0.03$, from test results on generators of that general type; also that the test SCR must be guaranteed to be not less than 0.80, as stated before.

$$**\sigma = \sqrt{\frac{(X_1 - \overline{X})^2 + (X_2 - \overline{X})^2 + \ldots\ldots\ldots (X_n - \overline{X})^2}{n}}$$

$X_1, X_2 \ldots\ldots\ldots X_n$ are observed values of the quantity

$\overline{X}$ = average value of the observations

n = number of observations

To fix one point on the margin-risk curve, assume a design which gives a calculated SCR of 0.85. Then $\sigma_A = 0.03 \times 0.85 = 0.0255$. The margin between guaranteed and calculated SCR is $0.85 - 0.80 = 0.05$, or 1.96 standard deviations. From the lower curve in FIG. 15, there is a 2.5 per cent risk that a single test will lie below the calculated value minus $1.96\sigma_A$, or 0.80. Similar calculations lead to the complete margin-risk curve (FIG. 16).

Thus, having established the relationship between margin and risk, and the risk having been set by economic considerations, then the margin to be held and hence the generator design can be intelligently set. If a risk of 5 percent were justified in the case just considered, then the correct calculated short-circuit ratio is 0.84. With this goal in mind, the designer uses such materials or other design factors as will yield a generator with a calculated short-circuit ratio of approximately 0.84. (It should be noted that, in order to achieve the best over-all design, relatively large risks and small margins should be chosen for the less important performance quantities, such as SCR, to favor the more important performance quantities, such as heating.)

Not all deviations in processes or formula errors follow an exact normal chance distribution. In fact, a normal distribution is somewhat uncommon for individual causes. However, the combination of a number of contributing causes usually does result in a normal distribution for the over-all tested performance. Consequently curves based on normal distribution, such as FIG. 15, may usually be relied upon as a guide to the probable risk of a given guarantee. The normal distribution is relatively simple and easy to work with. Other mathematical distributions are available; however, which may be used in specific cases to more nearly approximate actual test distributions.

It is possible to break down the combined standard deviation σ_A into its component standard deviations to express separately the effects of testing, manufacturing, and formula variations. This is an extremely useful thing to do if sufficient tests are available. For that reason the procedure is presented briefly here.

Testing variations can be evaluated by testing one machine many times over a period of time. This is commonly not practical with heavy apparatus. Occasionally, however, a number of duplicate machines of one design are built and tested, so that the combined variations due to testing and to manufacturing can be evaluated. To do this, the tests are expressed as the following ratio:

$$B = \frac{\text{Individual test on one generator}}{\text{Average of tests on generators of that design}}$$

The average value of this ratio, $\overline{X}_B$, is by definition unity. The standard deviation σ_B is a measure of the combined variations due to testing and manufacturing.

It is also possible to evaluate the variations due to formula error, if a number of generators of each of

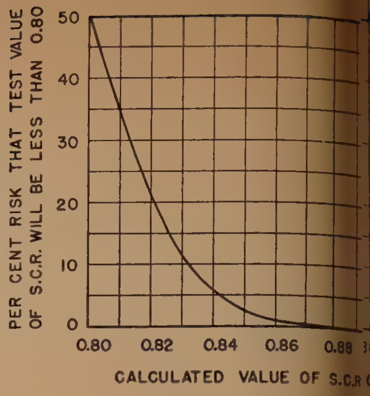

Fig. 16. Per cent risk that a test value of SCR (short circuit ratio) will be less than the guaranteed value (in this instance, 0.80)

several designs can be tested. For each design we a tain one value of the ratio:

$$C = \frac{\text{Average of tests on generators of that desig}}{\text{Calculated value for generators of that desig}}$$

If the formulas are correct on the average, the a age value of this ratio, $\overline{X}_C$ will be unity. If it is no constant may be added to the formula for convenie to make $\overline{X}_C = 1.0$. In any case, deviations of this ra from its average consist only of formula errors. ' standard deviation is σ_C.

It is useful to recognize that the product of the ra B and C is the ratio A considered earlier. Thus,

$$A = B \times C = \frac{\text{Individual test on one generator}}{\text{Calculated value for generators of that des}}$$

The average value of this ratio is $\overline{X}_A$. The standard viation, σ_A, is related to σ_B and σ_C as follows:(1)

$$\sigma_A = \sigma_{BC} = \sqrt{\overline{X}_B^2 \sigma_C^2 + \overline{X}_C^2 \sigma_B^2 + \sigma_B^2 \sigma_C^2}$$

The third term is ordinarily negligible, so that wh

$$\overline{X}_B = \overline{X}_C = 1.0, \quad \sigma_A = \sigma_{BC} \approx \sqrt{\sigma_B^2 + \sigma_C^2}$$

Thus, when any two of the variations due to testi and manufacturing, formula errors, or their combi tion can be expressed in terms of their standard dev tions, then the third can also be found. This is a va able means for directing efforts to reduce the compone errors as well as the combination error.

This is an example of the approach by means which good test equipment and modern analyti methods are co-ordinated to achieve optimum des for each generator performance characteristic.

Conclusion

Because of the great importance of turbine genera performance and reliability, great care must be tal to see that the generators provide the service expec of them. Performance of these machines is individua guaranteed, and they must meet their guarante This leads to a policy of obtaining excellent test equ ment, backed up by analytical design studies a statistical methods of data analysis, and using th elements to arrive at designs which give the custo the greatest possible value and assurance of quality.

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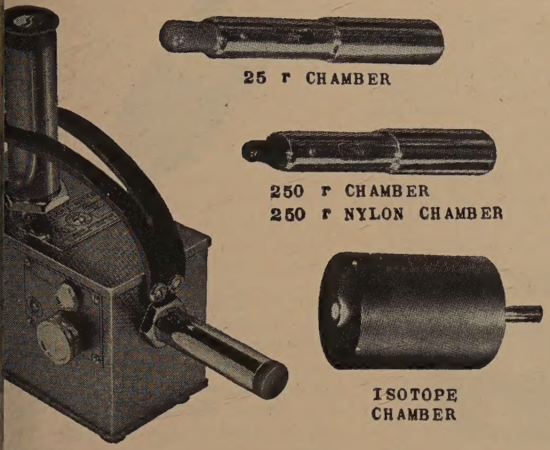
(1)W. D. Baten: *Mathematical Statistics*, John Wiley and S New York, 1938, p. 266.

THE VICTOREEN CONDENSER r-METER

the accurate determination of x-radiation intensity



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er values
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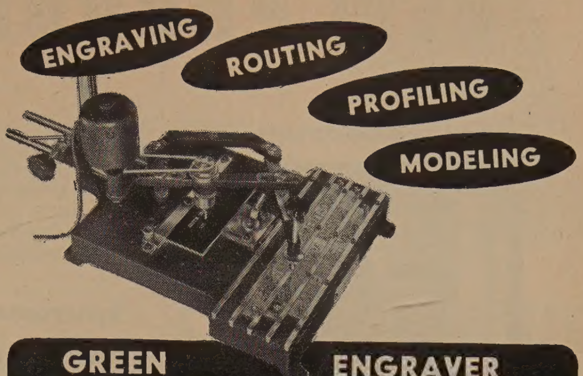

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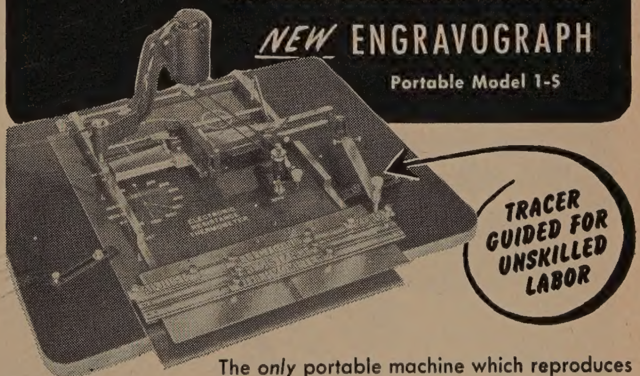

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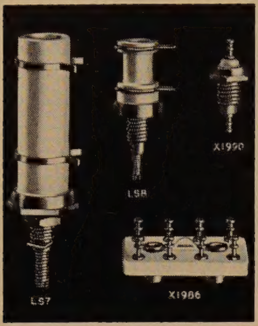
NEW PRODUCTS: AND WHAT THEIR MAKERS HAVE TO SAY ABOUT THEM

Ceramic Components



Four new ceramic components: Type LS-7 is a slug-tuned coil-form assembly with a ⅝-in. hex mounting base. It is equipped with adjustable ring terminals and has a spring lock for slug. It mounts in a single ¼-in. hole. All metal parts are nonferrous, heavily plated to withstand severe service conditions.

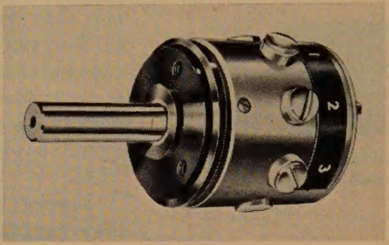
Type LS-8 is a slug-tuned coil form having silver-plated phosphor-bronze clip terminals which cannot loosen. It mounts in D punched hole or in ¼-in. round hole. All metallic parts except clips are cadmium plated.

Type X1990 is a feed-through insulator with a ⅜-in. hex bushing threaded for ¼-in. hole mounting. Voltage breakdown is 4800 volts, 60 cycles a-c.

Type X1986 is a terminal board. The assembly has eight terminals in 2 rows $\frac{9}{16}$ in. apart, plus two 4–40 tapped standoffs. A center ground strap is provided to which standoffs are riveted and soldered for good grounding at radio frequencies. All metal parts are nonferrous and heavily plated.—*Cambridge Thermionic Corporation 462 Concord Ave., Cambridge, Mass.*

Syncromount Potentiometer

The Syncromount, Type 85129, potentiometer offers long life and has a low-torque shaft mounted in ball bearings. This shaft with runout and concentricity within 0.001 in. of the syncro-type mount enables this potentiometer to be driven directly in a precision computer gear train. Its small size, 1⅛ in. diameter, makes it suitable for applications in guided missiles and aircraft installations where space is at a premium.



It can be furnished with linear or functional output. The total resistance can be as high as 100,000 ohms, with torque less than 0.2 in. oz.—*G. M. Giannini and Co., Pasadena 1, California.*

Power-factor Meter

A hook-on power-factor meter whic
mits direct measurement of power f
without cutting conductors or interru
electrical service. The Type AK-3 mete
be used on any balanced 3-phase circu
gives direct power-factor readings in cir

with voltages ranging from 100 to 600
and currents from 15 to 600 amp.
instrument is designed for use in indu
plants where maintenance of high p
factor is an important economic consi
tion. Small, light, and portable, the n
can be used to locate easily those cir
where corrective action is needed. To
ate the instrument, the user merely clip
voltage leads to the potential source, cl
the hook around the conductor, and ro
the selector dial to obtain the proper p
factor reading.—*General Electric Co.,*
and Instrument Divisions, West Lynn,

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3 NEW CERAMIC UNITS

LS-8 SLUG TUN COIL FORM. Featu silver-plated phosp bronze clip termi which cannot loos Height, 23/32″. Ma mum diameter, Mounts in punched hole or in round hole. Coil form of grade L-5 silicone pregnated ceramic. S is provided with a spring lock. All metallic pa except clips are cadmium plated. Supplied compl with slug and all mounting hardware.

X1986 CERAMIC TERMINAL BOARD. Gr L-5 silicone impregnated ceramic. 35/64″ O mounted height including terminals. 1¼″ length, width. Assembly has 8 C.T.C. Type X1558 termi in 2 rows (4 per row) 9/16″ apart, plus two 4-40 tap standoffs 3/16″ high on ⅝″ centers. A center grou strap is provided to which standoffs are riveted soldered for good grounding at R.F. frequenc Metal parts are non-ferrous, heavily plated.

X1990 CERAMIC FEED-THROUGH INSULATO Grade L-5 silicone impregnated ceramic. ⅞″ C length including through terminal. ⅜″ hex bush threaded for ¼″ hole mounting. Voltage breakdc 4800 volts R.M.S. @ 60 cycles AC.

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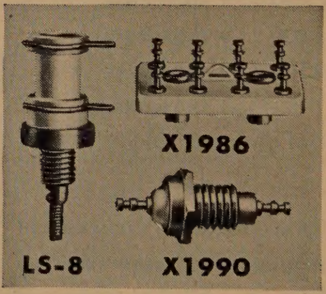
462 Concord Ave., Cambridge 38, Ma



BOOK REVIEWS

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L Chemicals
th, Donald B. Keyes, and Ronald
—John Wiley & Sons, New York.
pp. $8.00.

ndred and six industrial chemicals bed here logically, concisely, and n an ideal reference book for engineers in any industry, for g agents handling the purchase cals, and for anyone who sells to the Chemical Industry.

neral pattern of the description hemical proceeds in this order: n-flow sheets . . . reaction equa- . raw-material requirements . . . escription of manufacturing proc- processes, without the use of symbols . . . production and price vering the past 20 years . . . a d use pattern . . . miscellaneous economic aspects . . . and finally hich locates manufacturing plants ited States.

C. Dantsizen

AGNETIC Fields: Vol. I—Map-
ields
eber—John Wiley & Sons New
0. xiv+590 pp. $10.00.

I of this work concerns itself with ing of static electric and magnetic e stress is on the analytical ap- s may be seen from the following f the work.

st three chapters, fifteen percent ok, derive the fundamental rela- in the electrostatic and mag- fields and mention other analo- s. Chapters 4, 7, and 8, comprising percent, give fields for simple s and two- and three-dimensional olutions. The remaining 20 percent ok, Chapters 5 and 6, take up tal mapping and field-plotting The main emphasis here is on and geometrical methods. It is a rising that only the briefest men- ade of the powerful equivalent- ethod of field mapping which has ented by Kron and others.

F. J. Maginniss

Heat and Temperature Measurement
(2nd Edition)
Robert L. Weber—Prentice-Hall, New York. 1950. 422 pp. $6.65.

Methods and equipment for making thermal measurements, principally temperature, are expertly described in this book, primarily for the benefit of the technical student. Physical principles are discussed in Part I. A series of laboratory experiments, demonstrating these principles, comprise Part II.

The author's skill with short, concise sentences makes for easy reading through most of the many thorough chapters on temperature measurement. In the reviewer's opinion, the one short chapter on heat transfer attempts too great a coverage for the allotted space.

The young engineer as well as the student will receive many valuable assists from the numerous reference lists and the up-to-date tables of thermal properties contained in the appendix.

H. Robinson

Super-regenerative Receivers
J. R. Whitehead—Cambridge University Press, New York. 1950. 169 pp. $4.75.

This is the first book to be solely devoted to the super-regenerative circuit. Rapid advances in understanding and in design techniques were made during World War II, and what was originally a circuit with a reputation for unreliability became one which allowed the production of tens of thousands of stable, reproducible radar identification sets.

The book achieves a nice balance in covering a simple, lucid description of operating principles, a discussion of super-regeneration theory which involves a fair amount of mathematics, and a description of numerous super-regenerative circuits. Appendices, bibliography, and index are quite satisfactory. While the book is addressed primarily to the specialist, it will also be useful to those having a general interest in the subject.

C. G. Fick

TRADE LITERATURE

AL Tapes—The properties of four tape for construction and mainte- rk are given; 33 photographs illus- eir applications. Eight pages.—*a Mining and Manufacturing Co., uier St., St. Paul 6, Minn.*

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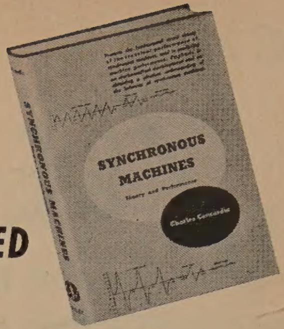
-type Batteries—A bulletin de- the constant voltage, long "shelf pact size, and other characteristics ercury-type battery. Included are specifications of all cells and bat- w in the line. Ten pages.—*P. R. & Co., Inc., Battery Div., North n, N. Y.*

Receiver—A catalog sheet describing a civil defense receiver for application wherever two-way radio systems exist. Specifications and features are given for the two types available—low- and high-band operation. Two pages.—*General Electric Co., Electronics Department, Electronics Park, Syracuse, New York.*

Viscorator Instruments—Presents a variety of viscorator instruments including the two-float, single-float, auto-sampling, cylindroplunger, and close-coupled types. Photographs and diagrams supplement the text. Twelve pages. Catalog 88.—*Fischer & Porter Co., Hatboro, Pa.*

Wave-shaping Device—A data sheet describing the Labmarker, a device for producing time marks in cathode-ray oscillography. Also gives data on Labcases and other components. Two pages.—*Berkshire Laboratories, 526 Lexington Road, Concord, Mass.*



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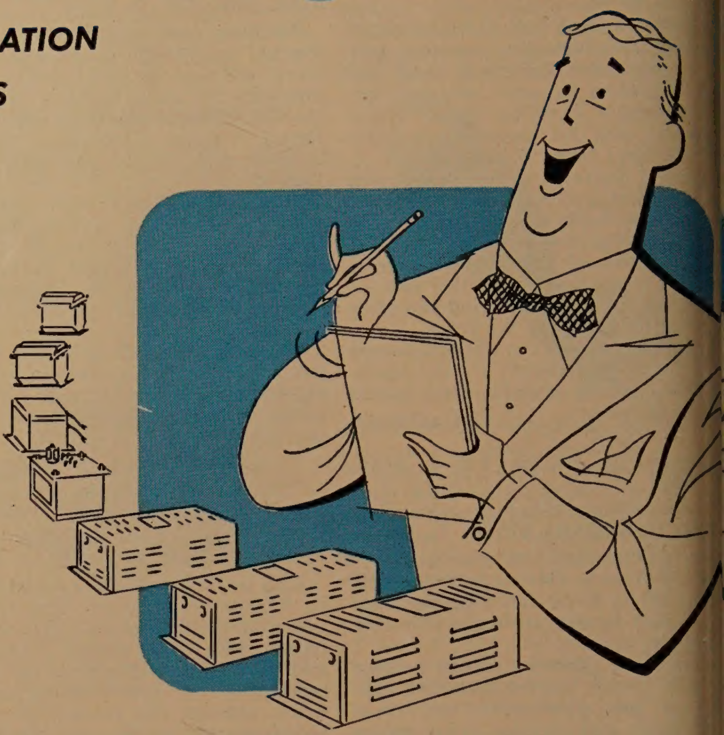

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